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पुस्तक संख्या
Book No. Kab 2nd ed.

PROFESSOR A. N. KABANOV

ANATOMY AND PHYSIOLOGY OF A HUMAN BEING

TEXT-BOOK FOR THE 8-th CLASS
OF THE SECONDARY SCHOOL

TRANSLATED BY A. JACOBSON AND P. KLATSKAYA

Second Edition, Revised

STATE TEXT-BOOK PUBLISHING HOUSE
OF THE MINISTRY OF EDUCATION OF THE R. S. F. S. R.
LENINGRAD BRANCH
Leningrad · 1955

9/с

Профессор А. Н. КАБАНОВ

УЧЕБНИК АНАТОМИИ
И
ФИЗИОЛОГИИ ЧЕЛОВЕКА

Для 8-го класса
средней школы

Утвержден
Министерством просвещения РСФСР

Издание седьмое

Предназначается для школ с преподаванием ряда предметов на иностранном языке и является переводом на английский язык Учебника анатомии и физиологии человека для 8-го класса средней школы.

Александр Николаевич Кабанов
Учебник анатомии и физиологии человека.
Для 8-го класса средней школы (на английском языке)
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Редактор *Э. Г. Андреева*
Тех. редактор *В. А. Макрушин*
Корректор *А. И. Варковецкая*
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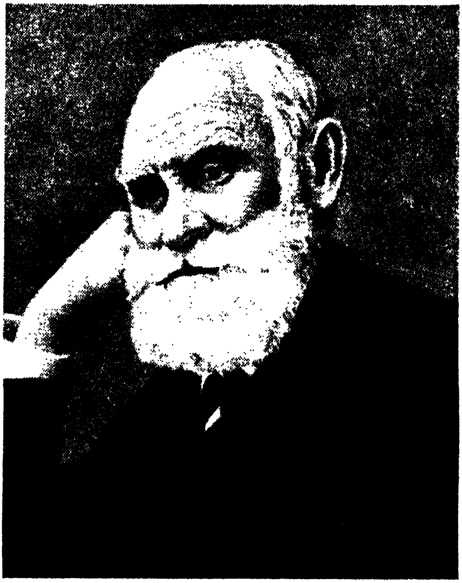
Сдано в набор 6/VI 1955 г. Подписано к печати 24/IX 1955 г. 60×92¹/₁₆. Печ. л. 16+вкл. 0,5. Уч.-изд. л. 18,75 + вкл. 0,73.
Тираж 8.800 экз. М-50008.
Ленинградское отделение Учпедгиза, Ленинград, Невский пр., 28.
Заказ № 178.
Министерство культуры СССР. Главное управление полиграфической промышленности. 2-я типография „Печатный Двор“ имени А. М. Горького. Ленинград, Гатчинская, 26.
Цена 3 р. 70 к.

I. P. PAVLOV'S LETTER TO THE YOUTH

"What would I desire for the youth of my country who are devoting themselves to science?

First of all — consecutiveness. I can never speak without agitation about this most important condition for fruitful scientific work. Consecutiveness, consecutiveness, and consecutiveness. From the very beginning of your work train yourselves to be strictly systematic in accumulating knowledge.



Study the ABC of science before you attempt to climb to its summits. Never proceed to the next stage before you have mastered the preceding one. Never try to cover up the shortcomings in your knowledge by even the most daring conjectures and hypotheses. No matter how much this soap bubble with its beautiful and ever changing colours may dazzle your eye, it will inevitably burst, and nothing will remain with you but confusion.

Train yourselves to discretion and patience. Learn to do the rough work of science. Study, compare, accumulate facts.

Perfect as the wing of a bird may be, it could never raise the bird aloft, if it were not supported by the air. Facts are air for the scientist. Without them you will never be able to fly upwards. Without them your "theories" will be useless efforts.

But while studying, experimenting, observing, try not to remain on the surface of facts. Do not turn into archivists of *facts. Try to penetrate into the secret of their origin. Seek persistently for the laws that govern them.*

The second is modesty. Never think that you already know everything. And no matter how highly esteemed you may be, always have the courage to say to yourself: I am ignorant.

Do not allow pride to take possession of you. Pride will make you stubborn in cases when it is necessary to give way; it will make you reject useful advice and friendly aid; because of pride you will lose your sense of objectivity.

Among the people with whom I work and whom I direct, it is the atmosphere that counts. We are all harnessed to one common task, and each propels it forward to the best of his power and ability. Among us it is often difficult to distinguish between "mine" and "thine," but our common task progresses all the more as a result.

The third is passion. Remember that science demands of a person his whole life. Even if you had two lives to give, that would still not be enough. Great effort and deep passion are required of a person by science. Be passionate in your work and in your investigations.

Our fatherland has opened up broad vistas to our scientists, and we must truthfully say that our country is generous in the support of science. Generous to the highest degree.

What can I say about the position of a young scientist in our country? Everything is perfectly clear. He is given much, but much is demanded of him. And it is a matter of honour for our youth, as well as for us, to justify the great hopes which our fatherland has placed on science."

I. P. Pavlov.

INTRODUCTION

1. Anatomy and physiology — sciences of the structure and functions of the organism

The problems of anatomy and physiology. Anatomy is the study of *the structure* of the organism; physiology is the study of the life processes, or, as they are usually called, *the vital functions* that go on in the organism.

The problems presented by these sciences are not restricted to the simple description of facts observed. Anatomy establishes the general laws of the structure of the whole organism, as well as of its separate organs, by revealing the dependence of their structure upon the functions performed by them. Physiology is the study of the interconnections existing between the different life phenomena, and also of the laws governing them, and their dependence upon the conditions of life of the organism.

The connection between structure and function. These two sciences — anatomy and physiology — are combined in the school curriculum, because they are so closely connected with each other. In order to understand the functions of the organs — in other words, the work of the organs, it is necessary to know their structure. And, vice versa, in order to understand the structure of the organs of the body, it is necessary to have a correct notion of their vital functions.

The connection between the structure of an organ and its function is so great that a change in the functioning of an organ causes changes also in its structure. In its turn, any change in the structure of an organ involves a corresponding change in its function.

A person who does gymnastics daily forces certain groups of muscles of his body to work intensively. As a result of the increase in function, the muscles increase in size and become stronger and firmer. On the other hand, muscles that are not exercised, as the result, for example, of some injury to the nerves leading to them, diminish in size and gradually degenerate; that is, they lose their normal structure.

The importance of experimentation. As a rule, the structure of an organism is studied *by dissecting corpses.* In order to investigate the life functions, it is necessary to make observations and *experiments*, that is, experiments only with the living organism, since the life processes cease after death.

Physiologists have been making experiments with animals for many centuries. Any operation may be performed on a dog, a rabbit or a frog: the heart, or any other organ, may be cut open and its work observed; experiments may be made with an isolated organ, that is, with an organ removed from the body (for example, the stomach, a muscle).

Experiments enable us to understand and to make a study of the separate organs. However, experiments unavoidably create unusual, artificial conditions of work with the organ that is being studied. Such artificial conditions are connected with the action of an anaesthetic (for example, ether or chloroform) on the organism, with the dissection of the animal's body, and chiefly with the destruction of the normal interconnection between the organs.

The great Russian physiologist, I. P. Pavlov (1849—1936), repeatedly stressed the following fact: it is possible to get a correct notion of the work of an organ only if it is studied under the natural conditions of the *whole*, unimpaired organism.

Such an approach to the study of the organism represents a new stage in the development of experimental physiology.

I. P. Pavlov was a remarkable experimenter. He mastered the technique of surgery to perfection and could perform complicated and ingenious operations on dogs — operations which enabled him to observe the functioning of the stomach, the liver and other organs under the conditions of the whole organism.

Thus, I. P. Pavlov conducted to the exterior of the body and grafted to the skin one of the ducts through which the pancreatic juice flows. When the wound healed completely and the animal was in a normal state again, experimenting could begin: for example, he gave the dog some special food and then determined the amount and the composition of the juice eliminated through the duct.

The study of the human organism also requires special conditions of experimentation. It is quite clear that not every experiment may be performed on a human being. However, most of the physiological processes going on in the body of a human being and in that of an animal are very much alike. Thus, in studying the physiology of the human being, it is possible to use experiments with animals as an auxiliary means, side by side with observations and experiments made on the organism of the human being. But, in doing this, one must never forget those most essential peculiarities which distinguish the human being from animals.

"Data," said Pavlov, "obtained from experiments with higher animals concerning the functioning of the heart, the stomach, and other organs, which are so similar to those of the human being, may be applied to the human being only with great caution; there must be a continual checking up to determine whether such similarities in the activity of these organs in a human being and in animals actually exist." When it is impossible to perform an experiment on a human being, the checking up that Pavlov speaks about is conducted by means of *observing* patients. Such observations are one of the principal methods of studying the physiology of a human being.

2. The importance of anatomy and physiology

Man's place in nature. Without a knowledge of anatomy and physiology it is impossible to have a correct understanding of man's place in nature, of his relationship to animals, of his origin and development. A scientific basis for the conception of man as one of the links in the unbroken chain of development of the animal world and of nature as a whole is possible only by making a study of the structure and functions of the organism.

In proving that man and animals have the same origin, anatomy and physiology destroy the religious myths about the creation of man by a god, and help to free people from superstitious beliefs and prejudices.

A study of the processes going on in the human organism has shown that these processes are always subjugated to the laws of nature, in particular to the law that operates in all nature, — the law of the conservation and transformation of matter and energy. This shows how unscientific and, consequently, how incorrect it is to try to explain the functioning of the organism by the existence of some secret "vital force" or "spirit."

The practical importance of anatomy and physiology. Both sciences — anatomy and physiology — came into existence and developed as a result of the practical needs of man. In order *to cure* a person of *a disease* and to be able *to safeguard* a healthy person *against disease*, it is necessary to know the structure of the organism and the processes going on in it.

Without a thorough knowledge of anatomy, a surgeon would not be able to perform highly complicated operations that require the penetration of the knife into any organ of the body — the heart, the brain, and the inside of the eye even.

A study of the various organs has led to successful methods of struggle with very many diseases, which were formerly considered incurable. The discovery of vitamins and the determination of their role have made it possible to find new reliable methods of treating and curing such diseases as scurvy, rickets, and others.

The successful application of blood transfusion, which in many cases has saved the life of a patient, became possible as a result of the study of the properties of the blood.

A thorough investigation of the protective properties of the organism has led to remarkable discoveries in the field of struggle against contagious diseases, and in their prevention.

The rules of *individual* as well as *public hygiene,* the observance of which is extremely necessary for the preservation of health, are based on the knowledge of anatomy and physiology. Many questions connected with the proper conditions of nutrition, with the general improvement of the sanatory conditions of work and of living, with the organization of the fight against fatigue, have been solved on the basis of the achievements in physiology. Physiology is extremely important for ***the proper organization of physical and mental labour,*** for the establishment of the most expedient alternation of work and rest. In many cases, fatigue has been reduced and labour productivity increased as the result of a thorough study, by physiologists, of the modes of work and of the influences exerted on the organism by the conditions of labour.

3. The contribution of Russian science to the development of anatomy and physiology

Russian scientists have played a great role in the development of anatomy and physiology. The services rendered by our own native science in the study of higher nervous activity are especially great. In the middle of the last century, I. M. Setchenov (1829—1905), one of the greatest of Russian scientists, made the first attempt to give a physiological explanation of psychical activity, or, as it is called, spiritual activity. He pointed out that physiology "holds in its hands the key to the true scientific analysis of psychical phenomena."

A number of years later, another great Russian scientist, I. P. Pavlov, made a study of the work of the higher division of the brain — the cortex of the cerebral hemispheres — and definitely established the fact that psychical activity is the result of the physiological work of the cerebrum.

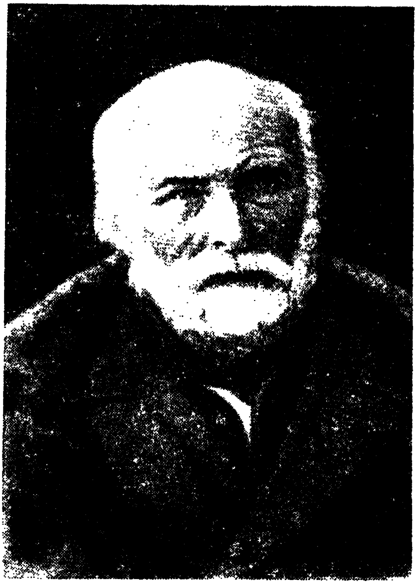
Pavlov's work with higher nervous activity opened up a new field of study in physiology along advanced lines; this created a revolution in biology and medicine, and has also played a vast role in strengthening the Marxian materialistic, in other words, the correct scientific world outlook.

A short time before his death Pavlov, having in mind the results of the physiological study of higher nervous activity, wrote:

"We have won for the mighty power of physiological research the whole animal organism, indivisibly, instead of only half. And this is completely our Russian irrefutable contribution to world science, to human thought as a whole."

I. P. Pavlov always claimed that science must not be separated from practical life, that science must serve the people. Interest in questions pertaining to practice is a characteristic feature of our greatest scientists. In the first half of the 19th century, Russian scientists were already making a study of problems connected with blood transfusion and with the application of narcosis. I. M. Setchenov was constantly interested in problems of physiology related to practical life. He made a study of fatigue and of the methods of fighting it, and he is rightly considered to be one of the founders of the physiology of labour. I. P. Pavlov always tried to put his scientific discoveries into practice and, especially, to apply them in the treatment of patients.

In the interests of surgical practice, N. I. Pirogov (1810—1881), an outstanding Russian scientist, froze corpses, dissected them and then made a study of the interrelation between the organs and the tissues. His work in this field laid the foundation of a new science — topographical, or regional anatomy.



N. I. Pirogov

P. F. Lesgaft (1837—1909), one of the greatest Russian anatomists, did very much to establish physical education on a scientific basis. He created a new approach to anatomy by his study of the structure of each organ in relation to its function. He paid special attention to the fact that the structure and functions of the organism depend on the conditions of life and on the exercise of the organs.

Studying the questions of physical education exactly from that point of view, he worked out a system of exercises which could best develop the organism.

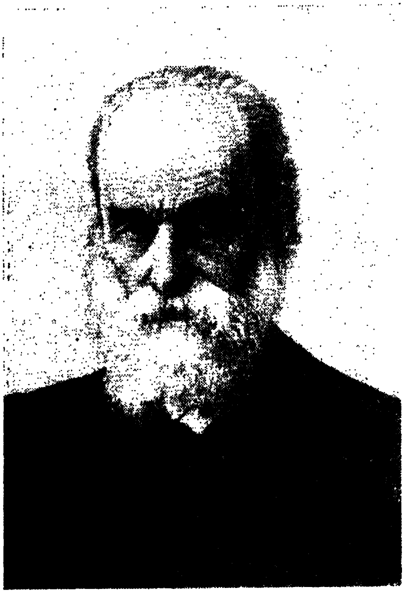
The work done by I. I. Metchnikov (1845—1916), one of the greatest scientists of our country, on the protective qualities of the blood, laid the foundation of the science of immunity, that is, of insusceptibility to contagious diseases.

Many Russian scientists, among them Pirogov, Lesgaft, Setchenov, Metchnikov and others, devoted all their powers to the service of the people. Thus, they became outstanding public figures and were persecuted by the tzarist government.

The achievements of Soviet science. Anatomy and physiology began to flourish as never before only after the Great October Socialist Revolution.

The Soviet Union has created special institutes and laboratories for the study of the human organism.

Pavlov and his numerous pupils and followers continued their study of the work of the nervous system, the digestive organs, the circulation of the blood, and enriched science with new discoveries, many of which are widely used in medicine to-day. Using, in particular, the study of higher nervous activity as a basis, scientists have been able to treat certain psychical and nervous diseases by means of prolonged sleep.



P. F. Lesgaft

Remarkable experiments have been made in the grafting of tissues, and even in the grafting of whole organs taken from another organism. A certain Soviet scientist succeeded in grafting into an animal a second heart, which, in its new location, continued to contract and to pump the blood normally.

V. P. Filatov, a Soviet professor, achieved great success in the grafting of tissues for healing purposes. He is successfully treating certain noxious diseases as, for example, lupus, or tuberculosis of the skin, by means of grafting on the patient pieces of skin cut from a dead body. It was found that the skin, like many other organs, retains its vital capacity long after the death of the person, and forms very active substances. The grafting of a piece of skin taken from a dead body activates not only the parts of the skin surrounding the grafted portion, but also other organs, forcing them to increase their resistance to the action of microbes. Recovery follows as a result.

The achievements of Soviet science in the study of cancerous growths and many other diseases are great.

I. THE ORGANISM AS A SINGLE INTEGRAL SYSTEM

4. The structure and chemical composition of living matter

The structure of an animal cell. The body of a human being, as well as that of an animal, is composed of cells. Each cell is a tiny microscopic organ, in which the life processes go on, and which fulfils definite life functions.

If different organs of the human or animal organism are examined under the microscope, an exceedingly great variety will be found in the forms, sizes and structures of cells. Nevertheless, it is also not difficult to note certain features that are common to all the cells (Fig. 1). Protoplasm[1] and a nucleus may be distinguished in each of the cells. *Protoplasm* is a semi-fluid mass, which makes up the chief bulk of the cell. It has an outer compact covering that has the appearance of a thin film; this is *the cell membrane*. Imbedded within the protoplasm is *the nucleus*, which is of a special structure and is separated from the surrounding protoplasm by a thin nuclear membrane.

The research work conducted for many years by the Soviet scientist O. B. Lepeshinskaya has proved that living matter does not always have a cellular structure. The life processes also go on in *non-cellular living matter*, which, under definite conditions, may acquire a cellular structure.

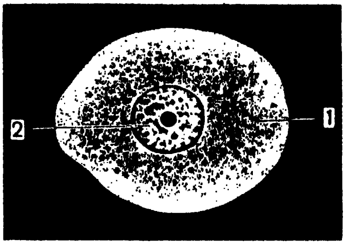


Fig. 1. An animal cell:
1 — protoplasm; *2* — nucleus.

The chemical composition of living matter. The study of the chemical composition of living matter leads to two very important conclusions.

Firstly, the substances composing living matter consist of carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine, potassium, sodium, calcium, iron, and many other elements, which also form inorganic compounds. There are no special elements of any kind that are peculiar only to living matter and that are not found in inorganic nature.

Secondly, the chemical compounds characteristic of living matter are of a very complex composition and are not to be found in inorganic nature. Most of the compounds peculiar only to the organism and called organic may be divided into three main groups: *proteins*, *fats*, *carbo-hydrates*.

Proteins. Proteins are the most complex of all known chemical compounds. Proteins form the chief constituents of living matter. Egg albumen (the white of egg) and gluten (the sticky substance in flour) are examples of proteins.

The necessary constituents of proteins are *carbon, hydrogen, oxygen, nitrogen, sulphur;* in addition, many proteins contain *phosphorus*, and various other elements in small quantities.

The molecules of proteins are huge in comparison with the molecules of other compounds: a protein molecule consists of hundreds of atoms. Proteins do not form real solutions. In real solutions, a substance breaks up into separate molecules, while in protein solutions each particle represents a whole group of molecules.

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[1] Derived from the Greek words: "protos" – first, original, and "plasma"— form, mould, i. e., something moulded.

An exceedingly important property of proteins is their instability. They are easily convertible; thus, for example, proteins curdle when heated and also when acted upon by acids and some other substances.

Fats. Only three elements enter into the composition of fats: *carbon, hydrogen* and *oxygen.* A molecule of fat is much smaller than a molecule of protein. However, a molecule of fat also consists of many atoms; the number of atoms contained in a molecule of the fats most commonly found in the human organism is about 150.

Fats are insoluble in water. If a small quantity of any kind of fat (for example, sunflower oil) is shaken in a test-tube full of water, or still better, in a weak solution of soda, the fat breaks up into such minute particles that it is impossible to see them with the naked eye. A substance containing a fat broken up in such a way, and subdivided into such minute particles, is called a *fat emulsion.* An example of a fat emulsion is milk, in which the separate particles of fat may be discerned only under the microscope.

When cells are examined under the microscope, very minute particles of fat[1] will often be found in them. However, the greater part of the cellular fat is contained in chemical compound with the proteins, and cannot be seen with the help of the microscope.

Besides fats, substances called lipides are of great importance in the structure and activity of cells. The lipides evidently take part in the formation of the outer membrane of the cell. Moreover, they are found in compound with the proteins of the cell.

Carbo-hydrates. The various forms of sugars (grape sugar, lactose, or milk sugar, cane sugar), starches and plant cellulose, are examples of carbo-hydrates.

Carbo-hydrates, like fats, are composed of *carbon, hydrogen* and *oxygen.* Usually, each molecule of carbo-hydrate contains twice as many atoms of hydrogen as oxygen, i. e., these elements are contained in the same proportion as in a molecule of water (H_2O). Thus, for example, the chemical composition of grape sugar or glucose, found in the blood is $C_6H_{12}O_6$. That is how carbo-hydrates received their name.

Carbo-hydrates either combine with the proteins of the cell to form a compound, or they form specific protoplasmic inclusions in the shape of tiny lumps of animal starch, or *glycogen.*

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[1] In order to distinguish the particles of fat from the numerous other particles in the protoplasm, the cell must be specially treated beforehand.

Animal and plant cells. We know from our course in botany that plant cells also contain protoplasm and a nucleus. However, they differ from animal cells in that they have an exceptionally compact covering consisting of the carbo-hydrate of *cellulose* and serving as the outer skeleton. Besides this, *little vacuoles filled with cellular juice* appear in the protoplasm of the plant cells during their growth. These little vacuoles gradually increase in size and occupy more space than the protoplasm itself (Fig. 2). Animal cells do not contain such juice.

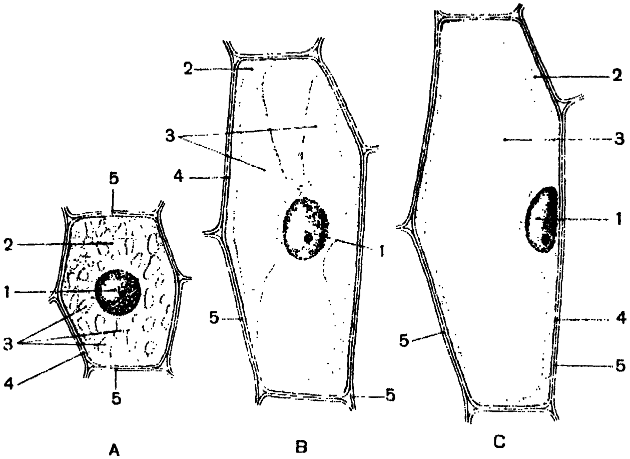

Fig. 2. Three successive stages in the development of a plant cell:

1 — nucleus; *2* — protoplasm; *3* — vacuoles containing the cell sap; *4* — cellulose membrane; *5* — membrane of the adjacent cell.

With the help of *chlorophyll* and the energy of the sun, the cells of green plants form complex organic compounds out of carbon dioxide and water. In this respect they differ greatly from animal cells, which cannot form organic compounds out of inorganic ones, and are in need of proteins, fats and carbo-hydrates.

5. Metabolism, or the interchange of substances, between the cell and its surrounding medium

Metabolism. Each living cell gets from the surrounding medium the nutritive material and oxygen that it needs. Within the cell the nutritive material undergoes changes and *is absorbed*, i. e., it is converted into the substance of the living cell. Alongside with this building up process, the substance of the living cell is constantly subjected to a partial *breaking down process* and to *oxi-*

dation. As a result, products are formed — among them carbon dioxide — that are eliminated on to the surface.

Thus, there is a continual, uninterrupted interchange of substances between the cell and its surrounding medium; when metabolism stops, life ceases. Metabolism also goes on in non-cellular living matter.

One of the most essential symptoms of life is *excitability*, i. e., the ability to respond to irritation, or, as it is usually said, to react to the various changes that go on in the surrounding medium.

The active, energetic condition that arises in the cell as the result of irritation is called *excitation.* Excitation is different in the different kinds of cells.

Excitability, as all other symptoms of life, disappears immediately if metabolism ceases.

The role of proteins. Of all the substances that enter into the composition of living matter, the most complex and the least stable are proteins.

The continuous chemical changes of the protein particles are the basis of metabolism and, consequently, also of life. When bodies in inorganic nature are subjected to chemical changes, they cease to exist: thus, iron that undergoes oxidation is converted into rust. In the case of proteins, however, the chemical changes that take place in metabolism are a necessary condition for their existence. When metabolism ceases, the proteins begin to decompose; in other words, they cease to exist.

"Life," says Engels, "is the mode of existence of protein bodies, the most essential factor of which is *the uninterrupted exchange of substances between protein bodies and the external world that surrounds them;* when this exchange of products ceases, life also ceases, which results in the decomposition of protein."

6. The reproduction of cells

The formation of new cells. In the middle of the last century it was ascertained that cells were reproduced by means of *division.* At first the nucleus divides into two equal parts, then the protoplasm divides, and thus two cells are formed out of one. Careful study has shown that, with rare exceptions, the division of cells is a very complex process, accompanied by changes in both the protoplasm and the nucleus, especially in the nucleus.

It was not so long ago that this process of division was considered the only means for the reproduction of cells. However, Lepeshinskaya has proved that under certain conditions cells may originate in non-cellular living matter also.

The method of making "cultures of tissues." It is very convenient to observe the reproduction of cells by the method of making cultures of living matter in a nutritive medium. Usually a thin piece of an organ is taken, no more than one square millimetre in size, and immersed in a drop of the liquid part of blood (plasma) or in a drop of liquid taken from embryonic tissue (for example, from the tissue of an embryonic hen developing in an egg).

Under proper conditions, the culture that has been immersed in a nutritive medium will show all signs of life. It consumes the nutritive material and eliminates the products of metabolism. The reproduction of the cells and the consequent growth of the whole piece of tissue may be observed under the microscope. If the nutritive medium is changed at the right time, it is possible to preserve the culture for many days. If a small piece of the growing culture is cut off from time to time and immersed in a fresh nutritive medium, the culture may be preserved for years. By means of such repeated transplanting, scientists have succeeded in prolonging, to the present day, the life of a piece of the heart taken from an embryonic hen in 1912.

Soviet scientists, utilizing the method of making cultures of tissues, are working on problems of great practical importance. They have had particular success in learning how the restoration of tissue takes place after an injury, and also what conditions most favour the rapid healing of wounds. The observations of Soviet scientists of the growth of malignant tumours, and especially those of cancer, are of vast significance to medical science.

Lepeshinskaya used the method of making cultures of tissues in her observations of the formation of cells out of non-cellular living matter. She broke up the cells of a fresh-water hydra by carefully grinding them in a mortar, and obtained living matter that had no cellular structure; this she immersed in a nutritive medium. Under these conditions she was able not only to watch, through the microscope, the appearance of tiny, barely visible spots, which gradually increased in size, forming little globules, but she also succeeded in photographing them. The globules continued to grow, developing into cells, with clearly defined nuclei and protoplasm; at the same time the cells became mobile and kept on dividing into two equal parts again and again.

The importance of the discovery of cell structure. The method of making cultures of tissues is one of the greatest achievements of contemporary science. It gives the possibility to make a study of living cells, not dead ones, and to observe the formation and development of the living cells. It has also considerably increased the importance of research work with the microscope. It was Engels who in 1858 emphasized the fact that the microscope played a decisive role in the development of physiology. He wrote to Marx: "The main fact that has revolutionized all physiology... is the discovery of the cell..." Almost thirty years later Engels again spoke about the discovery of the cell structure of organisms as a factor of vast significance: "Only after this discovery was made did the investigation of the organic living products of nature find solid ground... The veil wrapping in mystery the secret of the creation and growth and structure of organisms was thrust aside." The ever increasing success of research work with the microscope confirms the words of Engels.

The reproduction of the cells of the developing embryo. The development of the embryo begins with the division of the fertilized egg cell. Each of the two cells formed divides again into two equal parts. The cells subdivide over and over again, and their number keeps on increasing all the time.

The reproduction of the cells of the developing embryo proceeds also by means of their formation out of non-cellular living matter. Within the yolk of the egg there appear tiny "yolk globules," which can be seen only with the aid of a microscope, and which gradually acquire cellular structure.

Only at the very beginning of its development does the embryo consist of homogeneous cells. Very quickly the cells of the outer layer of the embryo become clearly differentiated from the cells forming the inner layer. Between the outer and inner layers appears a third — middle layer, which is also different from its two enclosing layers. These original layers of the cells, or *the germ layers,* represent the first rudiments of the various organs of the body.

The formation of tissues. The difference between the separate groups of cells gradually increases; the variety in their structure, which is connected with the physiological division of labour among them, becomes more and more clear. In place of the three original germ layers, there appear different groups of cells, which enter into the composition of the various organs and fulfil definite life functions. Such groups of cells, together with the non-cellular substance usually found in the spaces which separate the cells from one another, are called *tissues.*

7. The main groups of tissues

There are four chief groups of tissues: *epithelial, connective, muscle,* and *nervous* tissue.

Epithelial tissue. Epithelial, or covering, tissue (Fig. 3) covers and lines all the outer and inner surfaces of the body.

Epithelial tissue forms the outer layer of the skin, which serves *to protect the organism* against mechanical, chemical and other influences from the outside. The epithelium of the skin consists of several layers of cells.

A single layer of epithelial tissue lines the abdominal and thoracic cavities, and covers the outside surface of all the internal organs (the stomach, kidneys, etc.). Mucous membrane, which covers the mouth cavity, the windpipe, oesophagus, stomach, intestines and other organs, consists of epithelial tissue. Some of the cells of this membrane produce and secrete mucus, from which the membrane gets its name. Cells whose main function is to produce and secrete different kinds of substances are called *glandular cells*. Groups of such cells may form *glands*—organs which produce a definite kind of juice. The juice is eliminated from the glands through a duct, i. e., a little tube (Fig. 4).

A specific feature of the cells of the epithelial tissue is their arrangement side by side, in close contact with one another. Between the cells there are little bridges made of protoplasm, thanks to which the cells are closely connected with each other in their activity.

Connective tissue. Connective, or supporting, tissues are formed out of the middle germ layer and enter into the composition of almost all the organs of the body.

In the skin there is a layer of connective tissue which provides for its elasticity; under the skin it is the place where fatty matter is deposited.

The tendons of the muscles and the ligaments, which hold the bones of the skeleton together, consist of connective tissue. Cartilage and bone are also forms of connective tissue greatly changed.

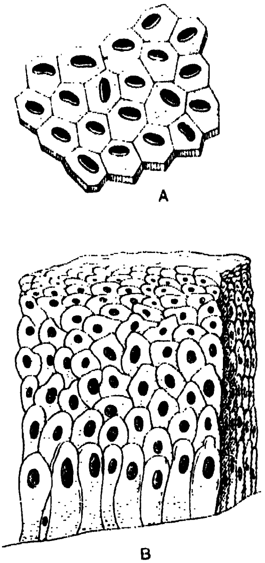

Fig. 3. A single layer of epithelium *(A)*; multi-layered epithelium *(B)*.

The cells of connective tissue are not in contact with one another. They are immersed in the intercellular substance which composes the chief mass of the tissue (Fig. 5).

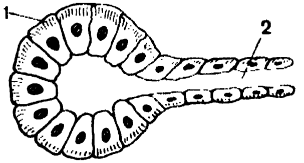

Fig. 4. Diagram of the structure of an ordinary gland: *1* — glandular cells; *2* — excretory duct.

Muscle tissue. Muscle tissue is closely related to connective tissue in its origin. Muscle tissue is formed almost exclusively out of the middle germ layer.

Muscle tissue reacts to any kind of stimulation (electricity, acid, pricking) by shortening, or, as it is usually called, by *a contraction*. This ability to contract, or *contractibility*, is the specific property of muscle tissue.

Muscle tissue composes more than one-third of the weight of the body. Not only the skeletal muscles, but also the muscles of the internal organs, as, for example, the stomach, the intestines, the urinary bladder, are composed of muscle tissue.

The muscles of the internal organs are called *smooth muscles* (Fig. 6). They consist of very elongated cells, each of which is

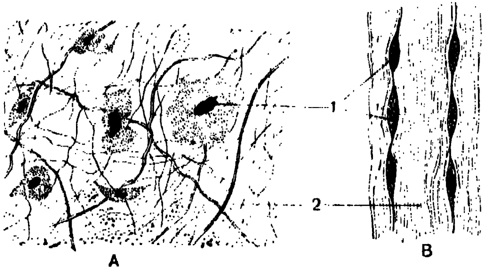

Fig. 5. Connective tissue.
A — fibrous tissue; *B* — tissue of a tendon:
1 — cells; *2* — intercellular substance.

not more than 0,1 or 0,2 millimetres in length, whereas the breadth is only several microns (a micron is equal to one-thousandth of

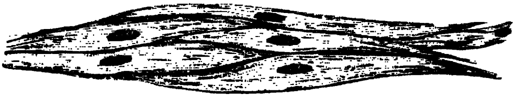

Fig. 6. Smooth muscle tissue.

a millimetre). Arranged longitudinally within the cells are extremely fine threads, or ***fibrils***, which slowly shorten when irritated, and in so doing bring about a contraction of the whole cell.

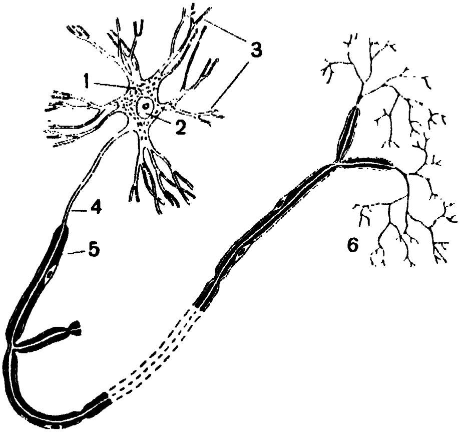

Fig. 7. Diagram of a neuron:
1 — body of a nerve cell; *2* — nucleus; *3* — branching projections (dendrites); *4* — axon, or neurite; *5* — sheath that, together with the axon, forms the nerve fibre; *6* — branching endings of the axon.

In comparison with the smooth muscles, the skeletal muscles have a more complex structure, possess a higher degree of excitability and contract much more quickly. We shall make a study of them in the following chapter.

Nervous tissue. Nervous tissue is formed out of the outer germ layer. The basic property of nervous tissue is its ability *to conduct excitation.*

Most of the nerve cells have several short branching projections called *dendrites,* and one long projection, or *axon.* The nerve cell with all its projections is called *a neuron* (Fig. 7). The long projections, enclosed in a sheath, are called *nerve fibres.* Uniting in little bundles, they form *the nerves.*

Specialization of tissues. The tissues of the human body are extremely varied. This is explained by the fact that the primary tissues become specialized in the process of long and complex development and are converted into the different tissues of the adult organism. The tissues keep on changing and increasing in complexity, not only during the period of the embryonic life of the human being, but also for a long time after birth.

Problem. Study special tissue preparations under the microscope and make a drawing of the structure of epithelial and connective tissues.

8. The organs and systems of organs

Organs of the body. An organism consists of organs, each of which has a definite structure and fulfils a definite function. The heart drives the blood through the blood vessels by means of its rhythmic contractions; the pancreas secretes digestive juice; the stomach digests food and pushes the food into the intestines by means of its contractions; all of these are organs. Their structure is very complex.

The special features in the structure of each organ are closely connected with the function which the organ fulfils.

Systems of organs. In conformity with the main functions of the organism, all the organs of the body are divided into several groups, or systems. In the human being there are the nervous system (the brain, the spinal cord, the nerves), the digestive system (the oesophagus, the stomach, the pancreas, etc.), the respiratory system (the larynx, the trachea, the bronchi, the lungs), the circulatory system (the heart, the blood vessels), the excretory system, the system of the organs of movement (the skeleton, the muscles) and others.

The location of the internal organs is shown in coloured plate I.

9. The organism as an integral whole

Isolated organs. Under certain conditions, an individual organ may exist also outside the organism, i. e., isolated from the rest of the body. Even several hours after death, signs of life may be detected in separate organs or in pieces of tissue, if favourable conditions are created so that the process of metabolism continues in them.

Kravkov, a Soviet scientist, cut off a finger from the hand of a corpse two days after the death of the person. With the help of a special apparatus, Kravkov injected a nutritive liquid saturated with oxygen into the blood vessels of the isolated finger. Observing the finger in the course of several days, he saw that the nail of the finger continued to grow and that the blood vessels retained their ability to constrict and dilate.

The unity of the organism. A study of the work of the separate organs is often made by isolating them from the organism. However, this method of study may be used only with the greatest caution. An isolated organ differs greatly from the same organ when it is an integral part of the whole organism. The whole organism represents *an integral system* in which all the organs are closely interconnected and have a mutual influence upon each other.

Each reaction of the organism to external or internal stimulations manifests itself in a *correlated* change of activity in the different organs of the body. Thus, while walking or running, the separate groups of muscles of the legs and of the trunk do not contract simultaneously, but in a strictly definite order; at the same time, the activity of the heart is intensified and accelerated, and respiration becomes more frequent, depending upon the needs of the organism. Changes also occur in the work of other organs of the body.

The interconnection and interactivity between the organs and, consequently, the unity of the organism, is maintained by the circulatory and nervous systems.

The circulatory system. The circulatory system, due to the unceasing movement of the blood in a circuit, provides for the interchange of products that goes on everywhere in the body between the blood and the tissues. Each organ, as a result of its activity, eliminates into the blood different kinds of substances which affect the work of other organs. Thus, chemical interconnection and chemical interactivity is established between the organs.

The nervous system. Coordination in the work of the organs, the strict subordination of their activity to the needs of the organism as a whole, is provided for by the nervous system. The nervous system consists of the spinal cord, the brain and a great number of nerves, which, like the blood vessels, extend to all parts of the body.

Each nerve usually has two kinds of nerve fibres: along one kind, excitation is transmitted from the various organs of the body to the central nervous system, that is, to the spinal cord and the brain; along the other, excitation is transmitted from the central nervous system to the working organs. The first type of fibres is called *centripetal,* or *afferent;* the second type — *centrifugal,* or *efferent.*

The process of excitation spreads along a nerve in waves, or *impulses*,[1] which travel separately, without merging with one another, as if they were momentary little shocks. Hundreds of impulses may be transmitted in the course of one second.

The short duration of impulses and the great speed with which they travel provide for precise and swift changes in the alternating reactions.

We have only to watch the performance of a violinist or a pianist to realize what perfection may be attained by quick movements, coming as the result of the contraction of dozens of muscles of the arms and hands.

Only by means of the nervous system can the organism respond swiftly to all possible changes arising in the external environment. Thus, for example, a sudden bright light, which irritates the endings of the afferent optic nerve, arouses in it excitation which is transmitted to the brain; from the brain, the excitation travels through the efferent nerves to the muscles, which contract, causing the eyes to close.

In the same way, food that is in the mouth irritates the endings of the gustatory nerves and, by means of the central nervous system, produces masticating movements and also secretion of saliva and of gastric juice.

Such reactions of the organism, arising in response to irritation and going on with the participation of the nervous system, are called *reflexes*, or *reflex actions*.

The reflex as the basis of nervous activity. Reflexes are the basis for the *regulating* activity of the nervous system. Every change that occurs in any organ of the body arouses, in the corresponding endings of the afferent nerves, excitation, which calls forth reflex actions in the different organs.

The leading role in bringing about the coordinated reactions of the organism is played by the higher division of the nervous system—*the cortex of the cerebral hemispheres*. Long years of research work conducted by I. P. Pavlov proved that there are two kinds of reflexes.

One kind of reflexes, called by Pavlov *unconditioned reflexes*, are constant; such reflexes are the jerking away of the hand when it is pricked, the secretion of saliva when food is taken into the mouth, the blinking of the eye at the sudden appearance of a bright light, etc. In animals, for example, in dogs, unconditioned reflexes are retained after the cerebral cortex has been completely removed. Only unconditioned reflexes were studied before the time of Pavlov.

The second type of reflexes, first studied by Pavlov and named by him *conditioned reflexes*, are acquired in the course of one's life and are not constant. Experiments with dogs have shown that conditioned reflexes disappear completely when the cerebral cortex is removed. Some examples of conditioned reflexes in the human being are the following: the secretion of saliva at the mere sight of food or at the mention of food, the jerking away of the hand from a wire at the words "the current is switched on" (although there has been no irritation of the hand by a current), and others.

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[1] From the Latin word "impulsus" meaning a blow, shock or sudden momentary movement.

Conditioned reflexes are the basis for higher nervous activity in the human being and in animals.

Three-fold nervous control. There are various ways in which the nervous system can influence the functioning of the organs. Pavlov speaks about a three-fold nervous control.

Firstly, nerve impulses may arouse or stop the activity of an organ. Thus, for example, by irritating certain nerves, it is possible to make a muscle contract, to cause the salivary gland to secrete juice, or to stop the contractions of the heart.

Secondly, nerve impulses may cause the constriction or dilation of the blood vessels in an organ. This brings about a decrease or increase in the flow of the blood. As a result of this, there are changes in the supply of oxygen and of nutritive substances, and in the elimination of the products of metabolism, all of which immediately influence the work of the organ.

Thirdly, the nervous system controls all the processes of metabolism which go on in the living organism. Any change in metabolism, called forth by the action of the nervous system, is sure to affect the work of an organ.

Such a three-fold nervous control provides for the rapid and exact adaptability of an organ to the needs of the organism.

The unity of the organism with the conditions of its existence. The great Russian biologist, I. V. Mitchurin, and his follower, T. D. Lysenko, showed that each organism requires definite conditions for the continuation of its life. Unity is established between the organism and the conditions of its existence; changes in the environment bring about corresponding changes in the structure and functions of an organism.

In his work of studying the unity of the organism with the conditions of its existence, Pavlov proved that the higher division of the nervous system—*the cortex of the cerebral hemispheres*—plays the leading role in the adaptability of the higher animals to the changing conditions of life.

Every change in the environment may lead to the formation of new conditioned reflexes, that is, it may lead to the appearance of new reactions of the organism, thanks to which animals are able to adapt themselves to the changing conditions of existence.

To a considerable extent, a person creates for himself the medium that surrounds him, and adjusts the conditions of life to his own needs. Therefore, changes in surrounding nature have very little influence on the human organism. It is the social environment in which a person lives and works that is of prime importance to him.

The Pavlov stage of the development of physiology. Three main features characterize the new Pavlov stage of the development of physiology:

1) the striving to study the work of the organs under the natural conditions of the whole organism; 2) the idea of *nervism,* that is, the acknowledgement that the regulation and correlation of the work of all the organs is accomplished by the nervous system; 3) the acknowledgement of the leading role of the cortex of the cerebral hemispheres in the activity of the organism, and in the interaction of the organism with the outer environment.

It is only *Pavlov's physiology* that gives scientists the possibility to study the organism in its unity with the conditions of existence.

REVIEW QUESTIONS

1. Enumerate the main groups of chemical compounds that enter into the composition of cells, and give their characteristics in short.
2. What are the similarities in the structure and functions of plant and animal cells? What are the differences?
3. What is metabolism?
4. How does Engels define life?
5. Explain the process of the reproduction of cells.
6. Name the four main groups of animal tissues and state their characteristics in short.
7. In what way is the unity of the organism expressed?
8. In what way is correlation in the work of the organism accomplished?
9. What is a reflex?
10. What is three-fold nervous control?

II. THE BONY-MUSCULAR SYSTEM

10. The composition, structure and properties of bones

The importance of the bony-muscular system. The bones of the skeleton provide the body with the necessary support, without which the body would not be able to preserve its shape.

The movable articulations of most of the bones enable them to produce movements related to one another. When the muscles attached to the bones contract, they maintain the separate parts of the skeleton firmly in their proper positions, or, on the contrary, set them into motion. Thus, the bony-muscular system provides for all the various positions and postures that the body may assume in space, as well as for all the possible kinds of movements that we are continually making.

In addition to this, the skeleton protects many important internal organs against shocks and pressure.

Cartilaginous and bony tissues. The skeleton appeared comparatively late in the process of the development of the animal world. The ancestors of contemporary vertebrates possessed *a cartilaginous skeleton.* The human embryo also has a cartilaginous skeleton at the beginning of its development, but later the cartilage gradually changes into *bone.* Only some bones (for example, most of the bones of the skull) do not pass through the cartilaginous stage, but develop directly out of primary connective tissue.

Cartilaginous tissue is a variety of connective tissue. The cells of cartilaginous tissue are found either singly or in small groups within a very dense, elastic intercellular substance (Fig. 8). In an adult person the cartilaginous tissue is preserved only in separate parts of the skeleton, mainly in the form of thin plates on the contacting surfaces of the movable articulations of the bones.

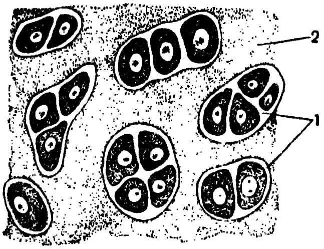


Fig. 8. Cartilaginous tissue:
1 – groups of cartilage cells; *2* – intercellular substance.

The cartilaginous tissue is gradually destroyed during the process in which the bony skeleton replaces the cartilaginous one. When the special kinds of cells multiply, they are converted into the cells of *bony tissue,* and at the same time produce fibrous intercellular substance.

The bundles of fibres of the intercellular substance assume the forms of thin *sheets,* or *layers,* which become quickly impregnated with salts of lime. These thin sheets arrange themselves in layers around the little canals that penetrate into the bony tissue. Blood vessels and nerves pass through these little canals. *The cells* of the bony tissue are situated between the bony sheets and are connected with one another by means of long projections (Fig. 9).

The resistability of bones. The resistability of bones is exceedingly great. It is true that even thick bones may be broken by a hard blow, but the bones can easily support heavy loads placed carefully on them. Some bones of the human body can bear a pressure of more than one thousand kilograms. Such resistability of bones is due to the specific character of their structure and of their chemical composition.

The bony sheets consist of *organic substances* and of *mineral matter* (chiefly lime salts, and first of all, phosphate of lime), with which they are impregnated.

The organic substance in bone provides for its elasticity, while the mineral matter gives it toughness. If the organic substance of a bone is burnt out on a hot coal-fire, the bone becomes brittle and crumbles into a powder even at the slightest pressure on it. But if a piece of bone is put into a weak solution of hydrochloric acid, the lime dissolves after some time, and the bone becomes as flexible as a rubber band.

In the course of life the composition of bone gradually changes. The dried bone of an adult person consists, approximately, of two-thirds of salts and one-third of organic substance. Such a composition provides the bones with great resistability.

In childhood the bones are considerably richer in organic substances, but, on the other hand, they contain a smaller quantity of salts. As a result, the bones of a child are more flexible and less brittle than those of a grown-up person. That is why children, especially little children, very seldom fracture their bones when injured.

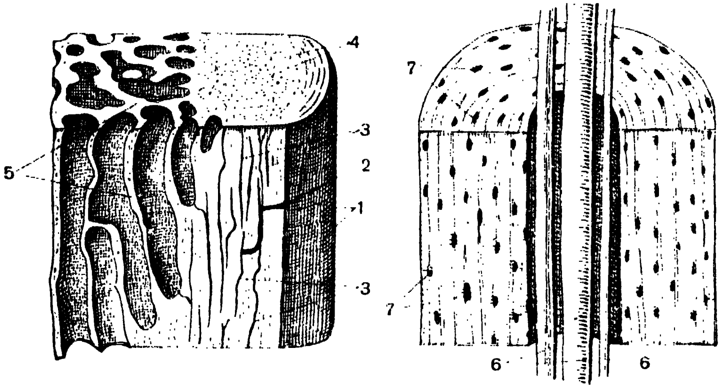


Fig. 9. Diagram of the structure of bony tissue (left — a piece of sawed off bone; right—the bone canal with the tissue surrounding it, highly magnified):

1 — outer surface of the bone; *2* — opening through which the blood vessels and nerves pass into the bone; *3* — longitudinal section of the canals of the bone; *4* — cross-section of the same canals; *5* — bone slats of spongy bone tissue; *6* — blood vessels and nerves inside the bone canal; *7* — bone cells (with bone plates between them).

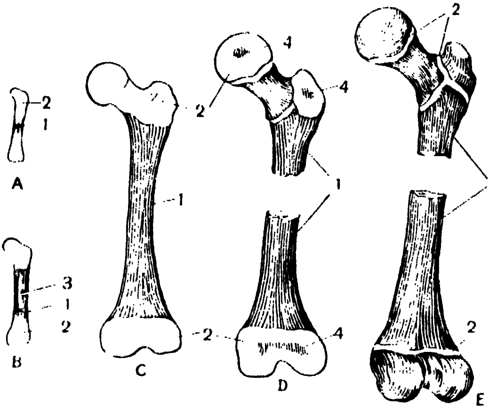
As one approaches old age, the bones become more and more impregnated with lime; at the same time, the content of the organic substances diminishes. The bones become harder and harder, but they also become more brittle. Due to this fact, old people are more liable to get fractured bones when they fall down or are injured.

The growth of bones. The bones are covered on the outside with a dense membrane — *the periosteum* — that adheres to it closely. The layer of periosteum that is in direct contact with the bone consists of cells which may develop into bony tissue. Multiplying by means of division, these cells provide for the growth of the bones and for their complete restoration in case of fractures.

In the growing bones of the extremities, between *the central part* of the bone and its ends, or *balls*, there are *layers of car-*

tilage, which disappear only at the age of 20 or 25. New bony tissue begins to form on the line of division between the central part of the bone and the cartilaginous layer, and, as a result, the bone grows in length (Fig. 10).

The bone grows in thickness by means of the stratification, on its surface, of the new bone cells which form the periosteum. During this process the inner layers of bony tissue are partially or completely destroyed. As a result of the destruction of the inner layers, the long bones of the skeleton assume, during their development, the appearance of thick-walled tubes. The *tubular* structure of the long bones does not diminish their resistability. The tube has almost the same resistability as a solid rod of the same thickness.



Of a new born child

Of a child 5–6 years old

Of a child 12–14 years old

Fig. 10. Thigh bone of the embryo and of a child at various stages of its growth:

A — of an embryo of 2 months; *B* — of an embryo of 3 months; *C* — of a new-born child; *D* — of a child 5–6 years old; *E* — of a child 12–14 years old; *1* — bony tissue in the central part of the bone; 2 — cartilaginous part of the bone; *3* — appearance of a cavity inside the central part of the bone; *4* — little islets of bony tissue at the ends of the bones.

The compact and spongy material of the bone. Only a partial breaking down of the bony tissue occurs inside the ends of the long tubular bones, and also inside most of the other bones (for example, the ribs, the vertebrae). If we take a cross-section of such bones, we see a multitude of thin bone *slats* with spaces between them, thanks to which the tissue is like a sponge in appearance.

The destruction of the bone material goes on most easily in those parts which are not subjected to compression and extension. And, vice versa, the bone material that is in the direction of action of these forces is not destroyed. As a result, the slats of each bone are arranged not accidentally, but in exact coordination with the direction of the forces which call forth compression and extension (Fig. 11). In other words, the inner structure of each bone is closely connected with its function. If the direction of the forces of compression and extension changes, a corresponding change begins in the arrangement of the slats. A similar re-arrangement of the bones may be observed, for example, after the amputation of a leg, and also after a prolonged illness, when a person has been confined to his bed for a long time and the bones become disaccustomed to the usual pressure of the weight of the body.

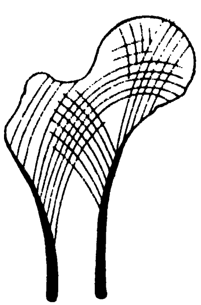


Fig. 11. Diagram of the arrangement of the bone slats in the upper end of the thigh bone.

Thus, the compact bony tissue is found almost exclusively on the surface of the bones. The deeper layers of bone consist of porous, or spongy, bony tissue.

The cavity inside the long bones and the spongy structure of all the other bones make the skeleton considerably lighter in weight, at the same time scarcely diminishing the resistability of the bones. If the whole skeleton consisted of compact bony tissue, it would be about twice or two and a half times as heavy.

Bone marrow. In proportion as the bony tissue breaks down, the cavities formed inside the bone fill up with *red marrow*, consisting of a special kind of connective tissue, very rich in blood vessels. The red marrow is a *blood-producing organ*: in it new blood corpuscles are formed.

In early childhood, red marrow is found in the spongy tissue of bone, as well as in the cavities of the tubular bones. As the child grows older, the red marrow in the cavities of the tubular bones is gradually replaced by fatty tissue, which is called *yellow marrow.*

Questions. 1. Why are curvature of the spine and deformations of other parts of the skeleton usually observed in children?

2. How can incorrect carriage of the body in walking and improper posture when sitting at one's desk affect the skeleton?

11. Articulations of bones

Fixed articulations. There are more than 200 bones in the body of a human being. These are connected with one another in various ways to form the skeleton. Articulations of bones may be of the following types: *fixed*, *semi-fixed*, and *movable* articulations, or *joints*.

The fixed articulations of bones may be formed by the *fusing together* of bones. Thus, in the first few years of a child's life the pelvic bone consists of three separate bones, articulated by thin layers of cartilage (Fig. 12). The latter are gradually replaced by bony tissue, and the bones fuse together.

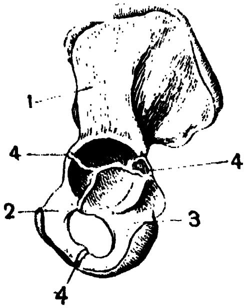


Fig. 12. Pelvic bone of a child:

1, 2, 3 — three bones which fuse together later; *4* — the cartilaginous layers between

The fixedness, or immovability, of the skull is due to the fact that each bone has a multitude of little projections, which fit exactly into corresponding hollows, or depressions, of the adjacent bone. Such an articulation of bones is called *a suture* (Fig. 13).

Semi-fixed articulations. Most of the bones have movable articulations. A small amount of movability is achieved by means of elastic *cartilaginous layers* between the bones.

Such cartilaginous layers are found between the separate vertebrae. When the muscles contract, these cartilaginous layers are also compressed, and the vertebrae are moved slightly towards one another. Therefore, when a person is in a reclining position and his muscles are relaxed, his body is somewhat longer than when he is standing. If the muscles of only one side of the spinal column contract, the

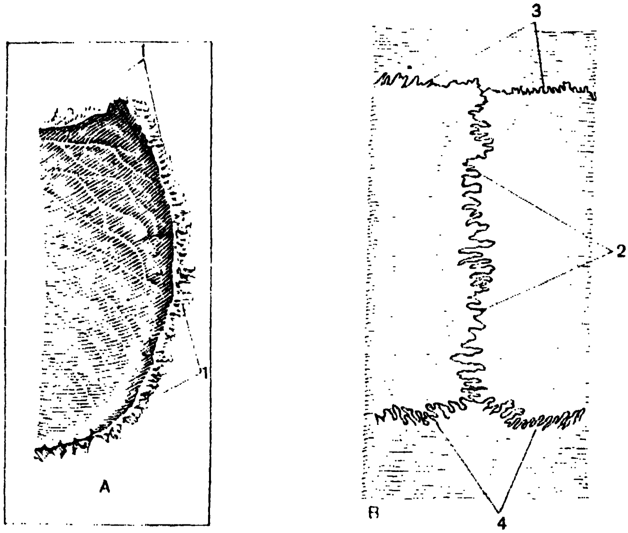


Fig. 13. Articulation of the bones by means of a suture:

A — part of the right parietal bone from within; *B* — part of the bones of the skull from without; *1* — edge of the parietal bone; *2* — suture between two parietal bones; *3* — suture between the frontal bone and the parietal bones; *4* — suture between the occipital bone and the parietal bones.

cartilaginous layers on that side are also compressed, and the edges of the vertebrae are moved closer together. On the opposite side of the body, the edges of the vertebrae, on the contrary, are moved slightly away from one another. As a result, the spinal column is bent in the direction of the contraction of the muscle (Fig. 14).

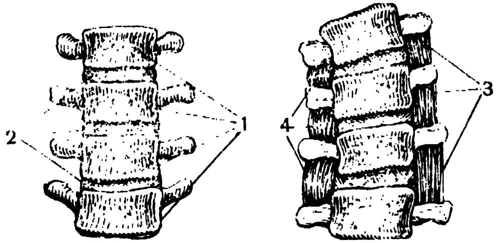


Fig. 14. Articulation of bones by means of cartilage:

1 — vertebrae; *2* — cartilaginous layers between the vertebrae; *3* — muscles between the vertebrae when the muscles are in a relaxed state; *4* — muscles between the vertebrae when the muscles are in a state of contraction.

Thus, the vertebrae, especially of the lumbar region and of the neck, can bend toward or away from one another. The spinal column, as a whole, allows for a considerable scope of movement and can be bent far forward, backward or sideways.

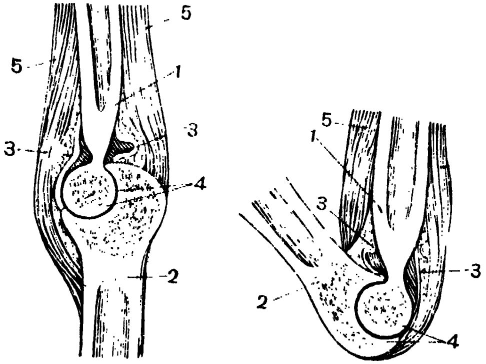


Fig. 15. Cross-section of the elbow joint showing the flexing and the extending of the arm at the elbow:

1 — humerus; *2* — ulna; *3* — joint capsule; *4* — joint surface of the bones covered with cartilage; *5* — muscles.

Joints. Joints are movable articulations of bones, formed by means of special capsules (Fig. 15).

The joint capsule consists of very compact connective tissue. Within the walls of the capsule and surrounding it, there are tough and tendinous *ligaments*. The edges of the capsule, together with the ligaments, grow fast to the bones at some distance from their contacting surfaces, and close *the cavity* of the joint hermetically.

The contacting, or *joint*, surfaces of the bones fit compactly together. They are covered with a layer of cartilaginous tissue. The smooth *cartilage* considerably lessens the friction between the bones, and thus facilitates their movement. The liquid, which is constantly being secreted on the inner surface of the capsule, also helps to lessen the friction, and therefore acts as a lubricator. Furthermore, the layers of elastic cartilage receive the impact of hard blows, thus safeguarding the body from any violent shocks.

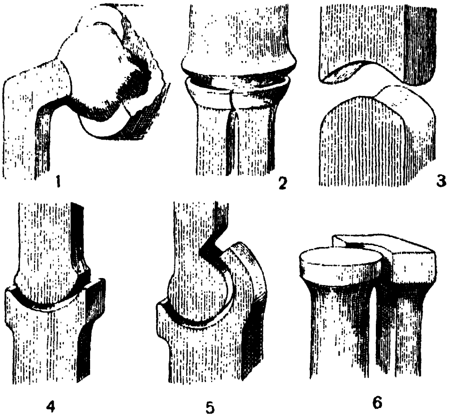


Fig. 16. Diagram of the chief forms of joint surfaces:

1 and *2* — spherical form (movement is possible in all directions); *3* - saddle-like form (movement is possible along two respective perpendicular planes); *4*, *5* and *6* — cylindrical form (movement is possible along one plane).

When the joint is subjected to a strain, a negative pressure is exerted in it, due to the fact that the cavity of the joint is hermetically closed. This negative pressure prevents the bones from moving apart and provides the joint with great resistability. If the joint capsule is pierced, air enters and no negative pressure is created. Therefore, a joint with a pierced capsule has considerable less resistability; if such a joint is violently strained, the bones are moved apart and a dislocation of the bones may occur easily.

By observing our own movements, it is not difficult to see that the movements in the various joints are different. Some joints allow for movement in *one plane* only (for example, bending and straightening); others permit movements along two *respective perpendicular planes* (for example, movement from side to side, as well as bending and straightening); a third kind provides for movement in *any direction* (bending and straightening, movement from side to side and rotating movements).

The range and direction of the movements depend on the forms of the joint surfaces.

Question. Explain why the exact measurements taken of a person's height in the morning will differ from those taken in the evening. When is a person "taller" — in the morning or in the evening?

Problem. By means of observations made on yourself, and by studying the bones of a skeleton, and also using figure 16, determine the dependence of movements on the forms of the joint surfaces of bones; then answer the following question: Which joints of the skeleton permit movements — a) in one plane, b) in two respective perpendicular planes, c) in any direction?

12. Dislocations and fractures of bones

Dislocations of joints. Any violent careless movement, a jump, fall or knock, may result in an injury to the skeleton: for example, in the dislocation or fracture of a bone. In case of a dislocation, the bones at a joint are wrenched from their proper positions, i. e., the ball of one bone slips out of the socket of another bone into which it fitted. When this happens, the ligaments are strained and are often even torn apart. Dislocations are often accompanied by severe pain, especially when an attempt is made to move the injured joint.

First aid in case of dislocations. If the aid rendered, in case of a dislocated bone, is not of the proper kind or is rendered too late, serious complications may set in. Therefore, two basic rules must be observed when giving first aid to an injured person: firstly, never attempt to set a bone or joint yourself; secondly, put the injured part of the body into the most comfortable position, so that it is in a state of rest and will not move, and then get the aid of a doctor immediately.

Fractures of bones. Fractures rarely occur in childhood and in early youth. The bones of middle-aged people, especially those of old people, are far more liable to be fractured; this is due to changes that take place in the composition of the bones as a person gets older. Sometimes, when there is an excessive reduction in the content of organic material, the bones become so brittle that even a slight knock, lifting up a heavy weight, or making some violent movement, may cause the bone to crack or may bring about a complete fracture.

First aid in case of fractures. In cases of fractures, as with dislocations, the first thing to do is to render first aid: the injured part of the body should be put into a position of complete rest, and should not be moved. This is all the more necessary in order to prevent the sharp ends or splinters of the fractured bone from tearing the skin and, what is still more dangerous, from doing any harm to the nerves and to blood vessels.

Bandage and splints are used to bind up a fractured bone. *Splints* are inserted in the bandage to prevent any movement of the injured part of the body. Thin wooden boards, strips of thick cardboard, sticks, small bundles of twigs, or other kinds of material of a suitable nature may be used as splints. Some soft padding should be placed between the body and the splint. The splints should extend beyond the border of the broken bone. Thus, in case of a fractured leg, the splint should extend from the heel to at least a part of the thigh; in case of a fractured thigh, one end of the splint should be on a level with the chest, and the other should extend to the lower part of the leg (Fig. 17). The splints should be bandaged tightly, but without any strong pressure on the injured part of the body. Clean pieces of cloth, towels or handkerchiefs may be used instead of bandage.

If no splints are to be had, the broken arm may be bandaged to the trunk of the body, and the broken leg to the other leg.

Sometimes, as the result of a fracture, the skin is torn away and an open wound is formed. In cases of such complicated or open fractures, it is necessary, first of all, to bandage the injured part to prevent any dirt from getting into the wound, and thus give it no opportunity to fester as a result of dirt.

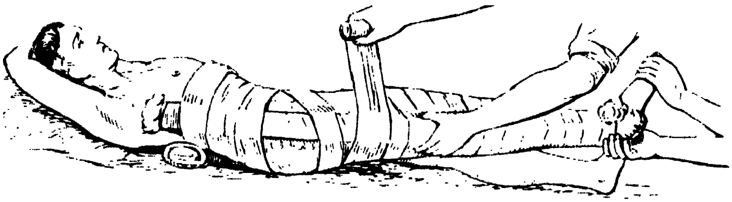


Fig. 17. Application of a splint in case of a fracture of the thigh.

In all cases when a fracture may be suspected to exist, the doctor should be called for immediately, or the injured person should be taken to the hospital after first aid has been rendered. It is also necessary to remember that the injured person should be carried or transported with the greatest care.

13. The structure of the human skeleton

The similarity in structure between the skeleton of the human being and that of animals. The common features in the structure of a human being and in that of vertebrate animals are especially striking when we compare their skeletons. The chief bones of even such animals as birds, reptiles and amphibians, which are so unlike man in appearance, are the same as those of man.

The spinal column, which consists of separate vertebrae, varying in number, is the main support of the skeleton of all these animals. There is much in common in the structure of the skull of all these animals. Even the extremities, which in various animals are so different in outward appearance as well as in function, have a structure that is common to all vertebrates. If we compare the flipper of a whale, the wing of a bird, the paw of a salamander and a mole with the hand of a human being (Fig. 18), we find the very same basic bones.

Such similarity in the structure of the skeleton of a human being and of the skeleton of vertebrates may be explained by the fact that they have a common origin. Differences arose under the influence of the dissimilar conditions of life in which the animals found themselves. The similarity between the human skeleton and the skeleton of his nearest of kin in the animal world — the man-like ape (Fig. 19 and 20) — is especially great.

Erect posture and working activity. In spite of the undoubtedly great similarities in the skeletons of all vertebrates, the human skeleton possesses some exceedingly essential peculiarities of its own. These peculiarities are closely connected with the transition of the ancestors of contemporary man to erect posture and to working activity.

All mammals, except the human being, support themselves on all four extremities in walking. Even the apes are not exceptions, for in locomotion they use not only their hind legs, but, to a greater or lesser extent, also their forelegs. It is true that in apes, the division in function between the hind legs and the forelegs is very clearly defined. With the help of their forelegs, apes build shelters and retreats for themselves and defend themselves from enemies by snatching up a stick or by throwing stones. But "never, and at no time," says Engels, "has the hand of an ape worked out even the rudest kind of a stone hatchet."

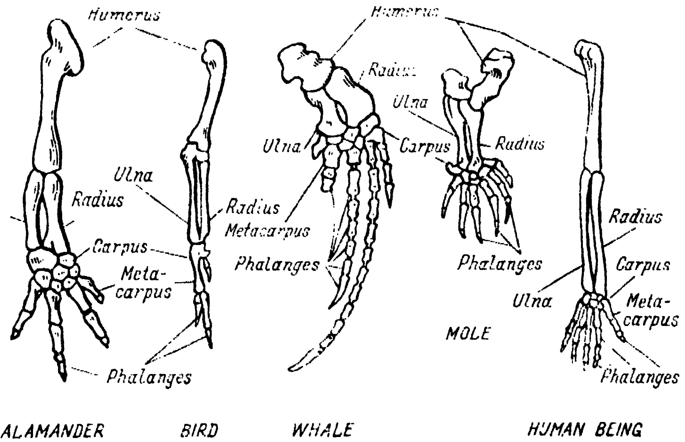


Fig. 18. Skeletons of the frontal extremities of various vertebrates.

As the result of changes in the conditions of life, the hand of the ape-like ancestors of man became gradually more and more free, and served him less and less often as a support in walking. The complete transition of the body to an upright position and to walking on two legs was the final step that freed the hand for work. The further perfection of the hand took place in the process of work and under the influence of work.

The transition to the upright position left its mark on the whole human skeleton.

The spinal column. The spinal column of a human being (Fig. 20) consists of 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 or 5 coccygeal, or caudal, vertebrae. The total number of vertebrae is 33 or 34.

A separate *vertebra* (Fig. 21) is *a bony ring* with a greatly thickened frontal part — *the body*, and with several *projections* to which the muscles are attached. Since the vertebrae are arranged one above the other, the rings of vertebrae form a tube, which holds the spinal cord. Between the bodies of adjoining vertebrae there are rather thick *cartilaginous layers*, thanks to which the spinal column possesses elasticity and mobility.

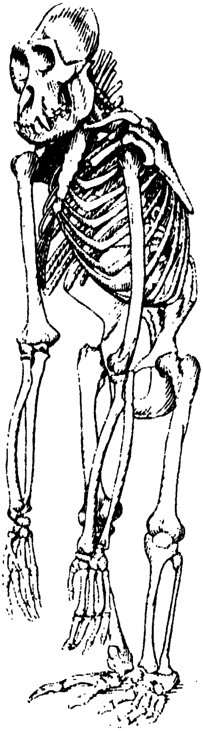


Fig. 19. Skeleton of an ape.

The sacral vertebrae begin to fuse together in childhood, and form a single *sacral bone*, *the sacrum*, in the adult.

In mammals, the great number of coccygeal vertebrae form the skeleton of the tail. The far-off ancestors of man also had a tail. As proof of this, we see the remains of the tail skeleton of the human being in the form of 4 or 5 undeveloped *coccygeal* vertebrae.

In animals, the spinal column extends along the trunk of the body in an almost straight line, forming only one cervical curve. The spinal column of a human being has thoracic, lumbar and sacral *curves* besides the cervical curve (Fig. 22); and it is these curves, formed as a result of the upright position of the body, that especially differentiate man from other vertebrates.

Because of these curves, the centre of gravity of a person standing is carried backwards and is on a perpendicular line, passing between the feet, nearer to the heels. Such a position of the centre of gravity helps to maintain the balance, and makes walking on two legs much easier.

The curves give more elasticity and flexibility to the spinal column. The spinal column acts like a spring in walking, running or jumping, or in making any violent movements; in this way it safeguards the head, and therefore also the brain, against shocks and concussions.

The thorax. The thoracic vertebrae take part in the formation of the thorax (Fig. 23). A pair of *ribs* extends from each thoracic vertebra, one on either side of it, and forms a movable articulation with the vertebra. The front ends of the ten upper pairs of ribs form articulations with the *sternum*, or *breast-bone*, by means of cartilage; moreover, the cartilages of the 8th, 9th and 10th pairs of ribs are fused together and articulated with the cartilage of the 7th pair. The 11th and 12th pairs of ribs are not attached to the sternum and have free ends.

The thorax protects the lungs, the heart, and also the organs of the upper part of the abdominal cavity, from shocks and injuries.

The thorax of the human being is wide, but it has a short diameter from front to back. Such a shape of the thorax is connected with the upright position of the body, and helps to maintain the equilibrium. Among quadrupeds, the thorax is narrower and longer, with a greater space between the spinal column and the sternum; the thorax is flattened, so to say, from side to side between the forelegs (Fig. 24).

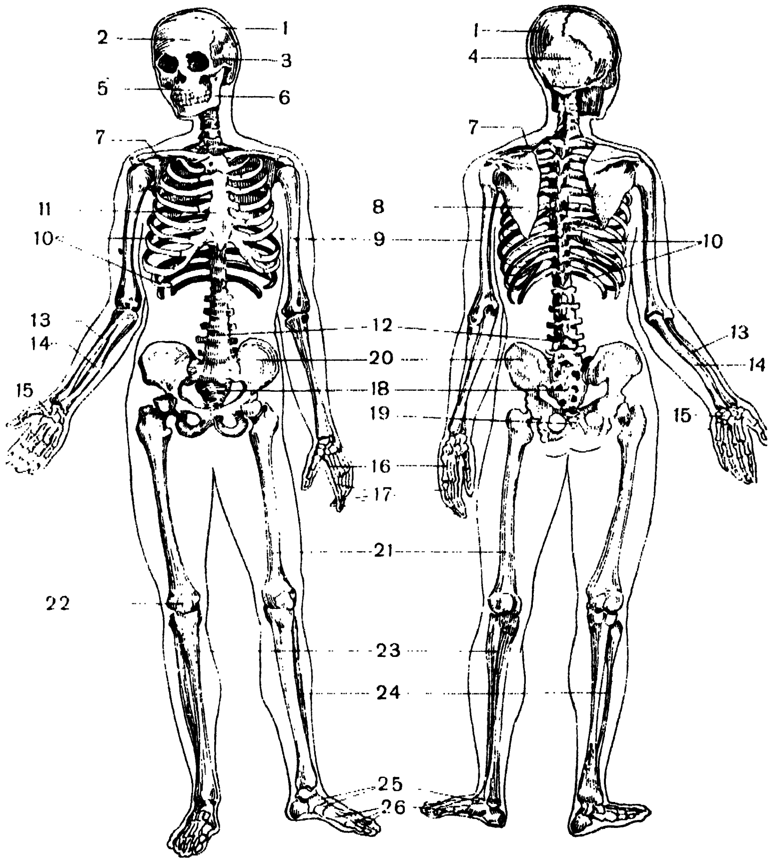


Fig. 20. Skeleton of a human being:

1 — parietal bone; *2* — frontal bone; *3* — temporal bone; *4* — occipital bone; *5* — upper jaw; *6* — lower jaw; *7* — clavicle; *8* — scapula; *9* — humerus; *10* — ribs; *11* — sternum (breast-bone); *12* — spinal column; *13* — radius; *14* — ulna; *15* — carpus; *16* — metacarpus; *17* — bones of the fingers; *18* — sacrum; *19* — coccyx; *20* — pelvic bones; *21* — femur; *22* — patella (knee-cap); *23* — tibia; *24* — fibula; *25* — tarsus; *26* — metatarsus, and the bones of the toes of the foot.

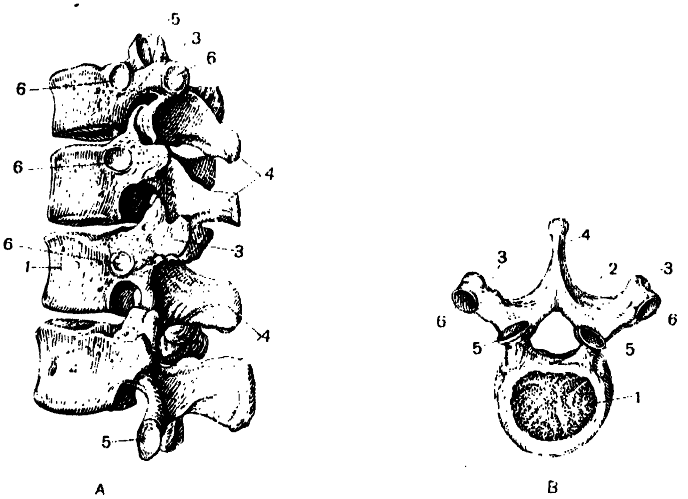


Fig. 21. Vertebrae (*A* — side view of three lower thoracic vertebrae and one upper lumbar vertebra; *B* — top view of a thoracic vertebra):

1 — body of the vertebra; *2* — arch of the vertebra; *3* — transverse projections; *4* — spinous projection; *5* — joint surfaces which connect one vertebra with another adjoining it; *6* — joint surfaces which connect a vertebra with a rib.

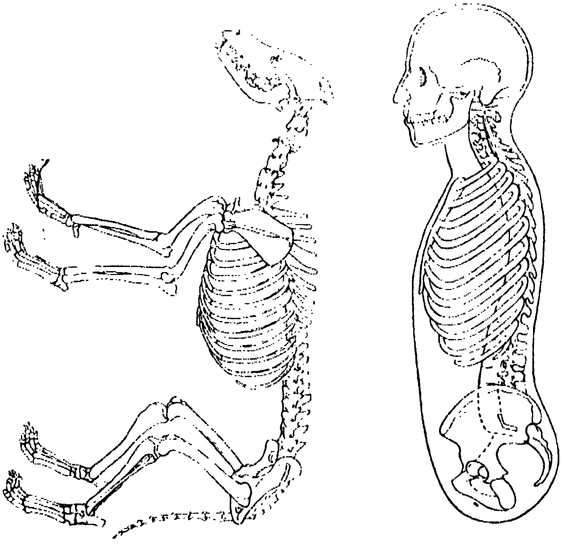


Fig. 22. Curves of the spinal column of a dog and of a human being.

The shoulder girdle and the pelvic girdle. In the upper part of the back there are two flat bones — *the scapulae*, or *shoulder blades;* they are attached to the spinal column and to the ribs only by means of muscles. Each scapula is articulated with *the clavicle*, or *collar-bone*, which, by its other free end, is articulated with the sternum.

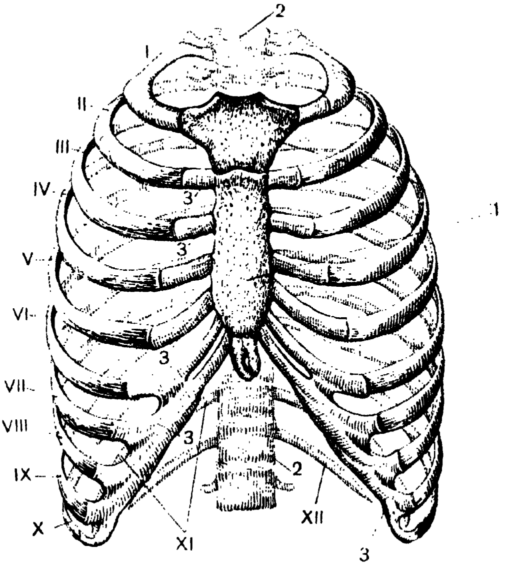


Fig. 23. Thorax:
1 — sternum (breast-bone); *2* — spinal column; *3* — cartilaginous parts of the ribs; *I—XII* — ribs.

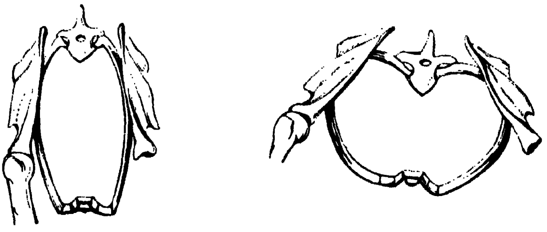

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Fig. 24. Diagram showing the difference in shape between the thorax of an animal and that of a human being:
1 — narrow thorax of a sheep; *2* — wide thorax of a human being, showing the short diameter from front to back.

The scapulae and clavicles encircle, as it were, the upper part of the trunk of the body, thus forming a girdle of the upper extrem-

ities — *the shoulder girdle.* The outer corners of the scapulae are articulated with the balls of the humeri of the arms.

The girdle of the lower extremities is the pelvic girdle, or pelvis. It consists of the sacrum and of the fixed articulations of two *pelvic bones,* which, in front, form fixed articulations also with one another. The pelvic bones, like the scapulae, have round sockets into which the balls of the femurs of the legs fit snugly.

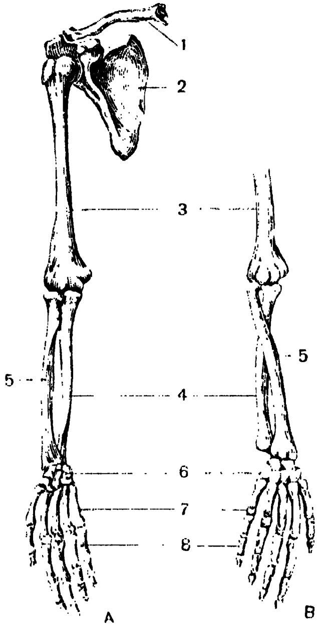


Fig. 25. Skeleton of the upper extremities, with the palm of the hand turned forward *(A)* and with the palm of the hand turned backward *(B)*:

1 — clavicle; *2* — scapula; *3* — humerus; *4* — ulna; *5* — radius; *6* — carpus; *7* — metacarpus; *8* — bones of the fingers.

The pelvis of a human being is wider than that of animals, and has the shape of a bowl. It is quite understandable why this is so. In animals, the viscera of the abdomen rest with all their weight on the walls of the stomach, whereas in man they are supported by the pelvic bones. Thus, the shape of the pelvic bones of a human being is connected with the upright position of the body.

The extremities. The bones of the upper and lower extremities have very much in common, although there are some differences also (Fig. 25 and 26).

In the upper extremity (the arm) we may find: 1) *the humerus,* forming a movable articulation with the scapula; 2) the forearm, consisting of two bones — *the ulna* and *the radius;* 3) the hand, composed of the small bones of *the carpus,* of the five long bones of *the metacarpus* and of *the bones of the finger* (two in the thumb and three in each of the four fingers).

We find corresponding parts in the lower extremity (the leg): 1) *the thigh (femur);* 2) the leg, consisting of *the tibia* and *the fibula;* 3) the foot, made up of *the bones* of *the tarsus, metatarsus* and of *the toes.*

The femur, together with the tibia, form *the knee joint,* to the front part of which adheres a little bone, called *the patella,* or *knee-cap.* The large projection of the upper part of the ulna, in the upper extremity, corresponds to the knee-cap.

If we compare the human arm with the foreleg of animals, we find that the joints in the human being are more movable than those in animals; the bones of the carpus and the metacarpus form the wide palm; the thumb is diametrically opposed to all the other digits. The differences in structure are the result of differences in function. Animals use their frontal extremities together with their hind extremities mainly for the purposes of locomotion, but the upper extremities of a human being are organs of work.

The legs are the organ of walking, and are the only support of the body when a person is standing. Therefore, all the bones of the legs are more massive than the bones of the arms, while the foot serves as a broad and stable support.

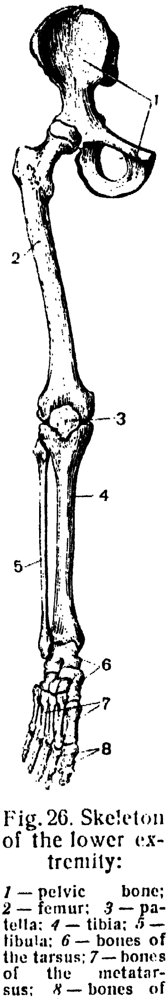


Fig. 26. Skeleton of the lower extremity:

1 — pelvic bone; *2* — femur; *3* — patella; *4* — tibia; *5* — fibula; *6* — bones of the tarsus; *7* — bones of the metatarsus; *8* — bones of the toes.

The skull. The skull has two main divisions (Fig. 27 and 28): firstly, the cranium, or the brainpan; secondly, the bones of the face.

The cranium forms a large cavity which holds the brain. The cranium is composed of the following bones: the *frontal* bone, two *parietal* bones, the *occipital* bone, two *temporal* bones, the *sphenoid* and *ethmoid* bones. All these bones form fixed articulations with one another by means of sutures. In the bones of the cranium there are a great number of tiny openings, through which the blood vessels and nerves pass. Within the temporal bone is situated the organ of hearing, into which a wide duct — *the external auditory meatus* — passes. The cranial cavity is connected with *the vertebral canal* by means of *the big opening of the occipital bone*. The spinal cord enters the brain on a level with the articulation of the upper cervical vertebra and the occipital bone.

The bones of the face form the bony framework of the upper parts of the respiratory and digestive organs. The bones of the face are composed of the upper and lower jaws, the cheek bones, the palatine bones, the vomer, the nasal bones, the lower nasal conchae and the lachrymal bones (Fig. 29).

The maxillary bones and *the palatine bones* form *the hard palate*, that is, the bony partition between *the nasal* and *mouth cavities*. All these bones, together with the *nasal bones*, form the side walls of the nasal cavity. *The vomer* and the lower part of *the ethmoid bone* divide the nasal cavity into right and left halves. The upper surface of the ethmoid bone has a great number of little openings, through which the olfactory nerves pass from the nasal cavity into the cranial cavity. The projections of the ethmoid bone form *the upper* and *middle nasal conchae; the lower nasal conchae* are separate little bones.

The cheek bones, uniting the upper jaw with the frontal and temporal bones, reinforce, as it were, the bones of the face.

The eye sockets, or *orbits*, are formed by several bones, namely: the maxillary bones, the frontal and cheek bones, the sphenoid, ethmoid and *lachrymal* bones.

The lower jaw is the only movable bone in the skull. Inside the lower and the upper jaw bones there are canals, through which blood vessels and nerves pass to the teeth.

Among animals, the bones of the face play a great role as an organ of attack, and of defence from enemies. This accounts, to a great extent, for the powerful development of the facial bones, the size and weight of which in many animals are greater than the size and weight of the cranium.

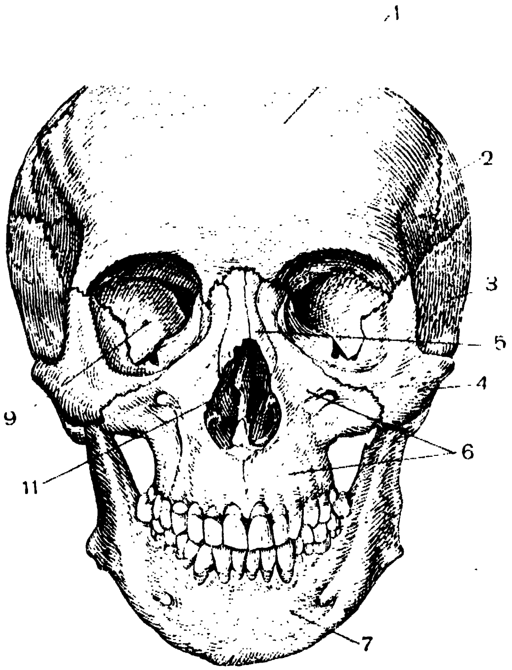


Fig. 27. Front view of the skull:

1 — frontal bone; *2* — parietal bone; *3* — temporal bone; *4* — zygomatic (cheek) bone; *5* — nasal bone; *6* — upper jaw; *7* — lower jaw; *9* — sphenoid bone; *11* — ethmoid bone.

With the transition of the ancestors of man to erect posture and with the liberation of the upper extremities, the bones of the face lost their role as an organ of attack and of defence. Likewise, the masticatory functions of the jaws became weaker when the custom of preparing food before eating it came into existence. In contrast to this, the brain, which plays such an important role in working activity, underwent a very high development. It achieved dimensions far exceeding the size of the brain in animals.

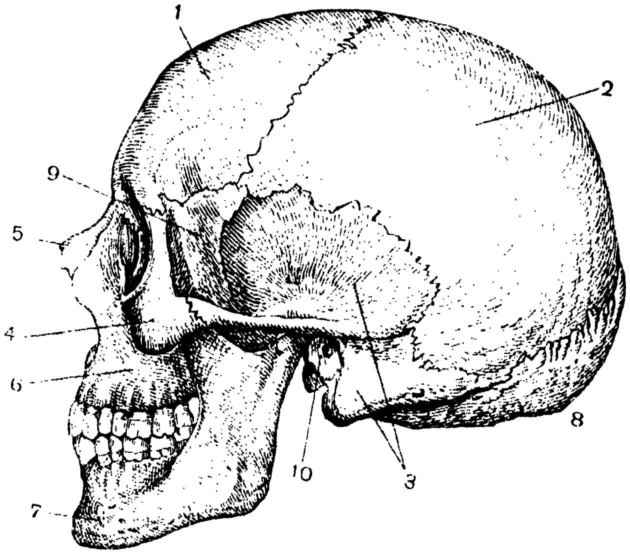


Fig. 28. Side view of the skull:

1 — frontal bone; *2* — parietal bone; *3* — temporal bone; *4* — zygomatic (cheek) bone; *5* — nasal bone; *6* — upper jaw; *7* — lower jaw; *8* — occipital bone; *9* — sphenoid bone; *10* — auditory opening.

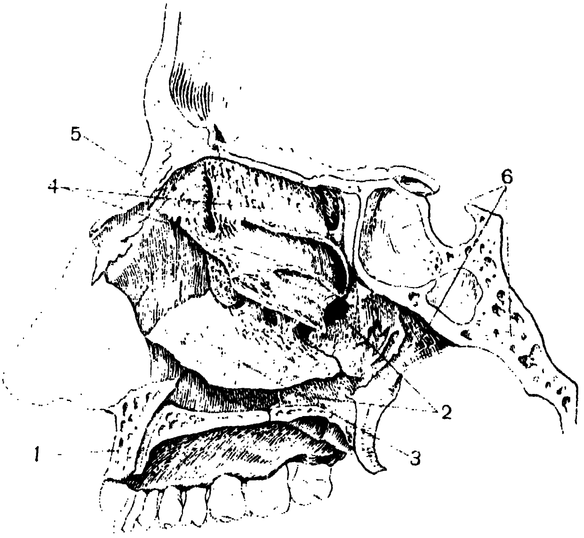


Fig. 29. Cross-section of the facial part of the skull:

1 — upper jaw; 2 — palatine bone; 3 — lower nasal concha; 4 — upper and middle nasal conchae; 5 — nasal bone; 6 — sphenoid bone.

All this led, on the one hand, to the poor development of the facial bones, particularly of the jaws, and, on the other hand, to the powerful development of the cranium.

When the body is in a horizontal position, the head naturally hangs down. In animals, the head, with the large and heavy bones of the face, is supported by strong occipital muscles. On the surface of the animal skull there are large projections and ridges that serve to strengthen the occipital muscles, as well as the strong masticatory muscles.

The head of a human being is supported at the base. When the head is held in an upright position, its centre of gravity is moved very slightly to the front of the point of support. Although the head of a human being falls forward when the muscles are relaxed, no great strain of the muscles is needed to support the head in its proper position. This explains the poor development of the occipital muscles in the human being. The masticatory muscles are also poorly developed and correspond to the comparatively small size of the lower jaw. Due to the absence of strong muscles, the surface of the human skull has no large projections and ridges on it.

Question. What parts of the skeleton serve as a protection to the organs and what organs does the skeleton protect?

14. The structure and properties of skeletal muscles

The structure of a skeletal muscle. In the beginning, the skeletal muscles of the embryo differ very little from the smooth muscles. Then the muscle cells begin to develop very quickly, sometimes growing to a length of 10 to 12 centimetres; during this growth the nucleus keeps on dividing repeatedly. As a result, a long muscle fibre is formed, which contains many nuclei and thus cannot be called a cell any longer.

The fibre of the skeletal muscle is made up, as it were, of a great number of cells that are inseparable from each other. Such a complex structure, in which it is impossible to separate the individual cells, is called *syncytial structure.*

All the protoplasm of the muscle fibre is almost completely filled up with very minute fibrils, which extend through the whole length of the muscle fibre. When examined under the microscope, the fibrils are found to consist of evenly alternating bands, one of which is of a light colour and the next of a dark colour. The light and the dark coloured bands of all the longitudinal fibrils lie on one transverse level, and the whole fibre is diametrically crossed with stripes (Fig. 30). That is why the skeletal muscles are called *cross-striated,* or *striated,* muscles.

The contraction of a muscle. The contraction of a muscle takes place as a result of the shortening (the contraction) of the dark sections of its fibres. When the muscle fibres shorten, they become thicker, like a rubber band that is released after it has been stretched. It is clear that the whole muscle becomes thicker and shorter when it contracts.

The smooth muscles possess a comparatively low degree of excitability, and contract very slowly. The striated muscles, on the contrary, are easily excited, and the process of contraction goes on with great rapidity in them. The skeletal muscles of a human being may contract more than 10 times a second, but the striated muscles of the wings of insects may contract 200 or even 300 times a second; however, it takes the muscles of the stomach and of the intestines, which consist of smooth fibres, several seconds to make one contraction.

The response of a muscle to stimulation. A muscle cut from the body of a frog contracts if it is pricked with a pin, hit with a pair of pincers, touched with a wire heated in the fire, subjected to the action of an electric current, or if a crystal of sodium chloride is placed on it. In other words, any stimulation — mechanical, thermic, electrical, chemical — brings about contraction in a muscle. The one important condition is that the stimulation should be of sufficient strength.

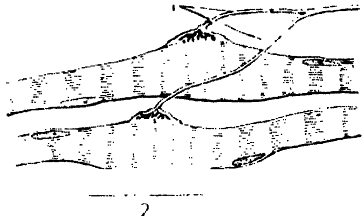


Fig. 30. Fibres of striated muscle:

1 — ending of a nerve fibre; *2* — part of the muscle fibre in a state of contraction.

The muscles of the living body may be subjected to the action of such artificial stimuli only in exceptional cases. The normal, natural stimuli of our muscles are nerve impulses.

This may be easily ascertained by an experiment with a skeletal muscle, together with the nerve leading to it, cut from the body of a frog.

The contraction of such a muscle can be readily observed, if one end of the piece of muscle is fixed tightly in place by a clamp, and the other end is attached, by means of a piece of thread, to a lever (Fig. 31). The movement of the lever will record, with great exactitude, each contraction of the muscle called forth in response to the stimulation of the nerve by an electric current.

The nerves which enter the muscles consist of a great number of nerve fibres. Inside the muscle, each fibre branches out many times, thus supplying nerve endings to a whole group of separate muscle fibres (Fig. 32).

Impulses from the endings of efferent nerve fibres are transmitted to the muscle fibres, and they contract. If there is a simultaneous excitation of all the fibres, the muscle contracts with the greatest force. If the wave of excitation affects only 50 or 25 per cent of the nerve fibres, the number of contracting muscle fibres and, consequently, the general force of the muscle contraction also, is reduced to one-half or one-fourth. A minimum contraction of the muscle takes place when only one nerve fibre is stimulated. The muscle responds to each wave of excitation travelling along the nerve by a contraction which, in most of our muscles, lasts about 0,1 of a second.

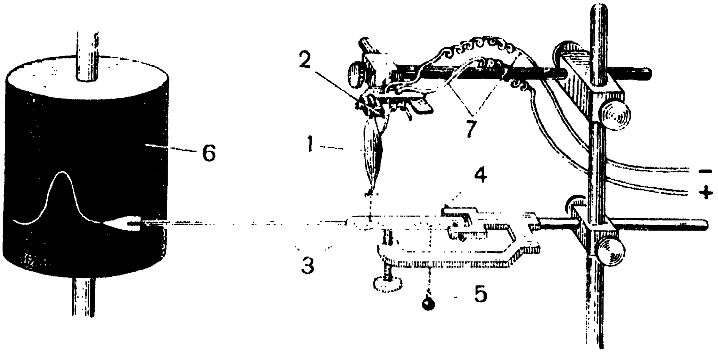


Fig. 31. Record of the contractions of a muscle of a frog on the blackened surface of a rotating drum:

1 — muscle with a nerve leading to it (*2*); *3* — lever which records the contractions on the drum of the kymograph (*6*); *4* — axis of rotation of the lever; *5* — load which pulls the lever down; *7* — electrodes on which lies the nerve; the connection of the electrodes with the source of the current is shown.

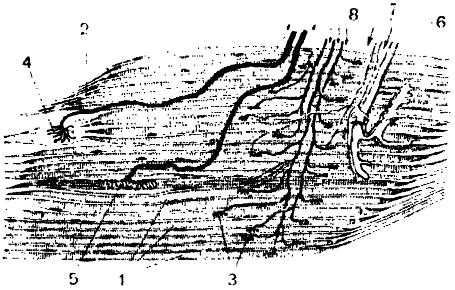


Fig. 32. Nerve endings in a skeletal muscle:

1 — muscle fibres; *2* — tendon of the muscle; *3* — endings of the efferent (motor) fibres; *4* and *5* — endings of the afferent (sensory) fibres in the tendon and in the muscle; *6* — blood vessel; *7* — nerve fibre leading to the vessel; *8* — nerve fibres influencing metabolism in the muscle.

Impulses coming from the central nervous system to a muscle always follow one another with great frequency, and the muscle has no time to relax after each of its contractions. This causes the separate contractions to merge into one long, or *tetanic*, contraction. These are the usual types of contractions of skeletal muscles which we may observe in any of the movements of our body.

The attachment of the muscles to the bones. Muscles which are attached by one or both of their ends to the bones of the skeleton are called *skeletal* muscles. They are covered with a thin elastic membrane. The muscle usually terminates, at each of its ends, in very strong white cords — *tendons*, which fuse together with the periosteum. In most cases, the two ends of the muscle are attached to two adjoining movable articulations of bones; sometimes the tendons extend over a long distance, passing over two or more joints (Fig. 33).

When the muscles contract, they shorten, and either produce movements of the body or maintain the body in a definite position.

Movements caused by the contractions of muscles. In the 17th century, scientists already looked upon the bones as *levers,* which were set into motion by the muscles. And, indeed, most of the movements of our body are produced on the principle of the lever, as the diagrams show.

Movements of the separate parts of the body are made most often according to the principle of a lever of the second order, in which the point of support is along the line that unites the points of the application of power and of resistance. In most cases, the point of attachment of a muscle is much nearer to the point of support than the centre of gravity. Therefore, the muscles must develop very great power in order to overcome the resistance. However, in so doing, there is a considerable gain in the scope of the movements.

Around a joint there are usually several muscles, each of which, in contracting, brings about some kind of a definite movement.

Due to the contraction of a dozen different muscles at the elbow joint, the forearm bends (or flexes) and straightens out (or extends) and the hand turns inwards and outwards (Fig. 34). The movement resulting from the contraction of each muscle depends on the location, on the bones, of the points of attachment of the muscle. Thus, when the brachial muscle, attached to the front surfaces of the humerus and ulna, contracts, it bends the elbow joint; the two-headed muscle (the biceps) of the upper arm, which is attached by its lower end to the inner surface of the radius, not only bends the elbow joint, but also turns the hand far outward with force; the three-headed muscle (the triceps) of the upper part of the arm is attached by its lower end to the posterior surface of the ulna and, in contracting, straightens out the arm at the elbow.

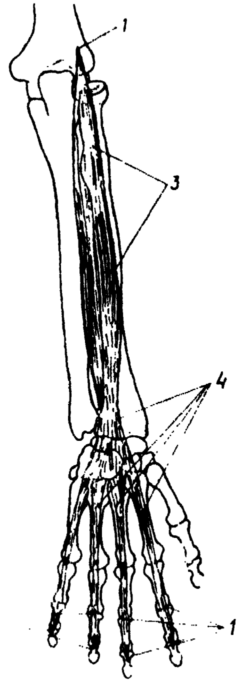


Fig. 33. Attachment to the bones of a muscle that straightens out the fingers of the hand:

1 — point where the muscle is attached to the lower end of the humerus; 2 — points where the muscles are attached to the bones of the fingers; *3* — a muscle; *4* — long tendon of the muscle.

The muscles located around a joint may contract either separately or simultaneously in one combination or another; simultaneous contractions occur most frequently. The variety of the movements produced by us is due to the variety in the combinations of the simultaneously contracting muscles. At the same time, the contracting power of each muscle taking part in the movement is of great significance.

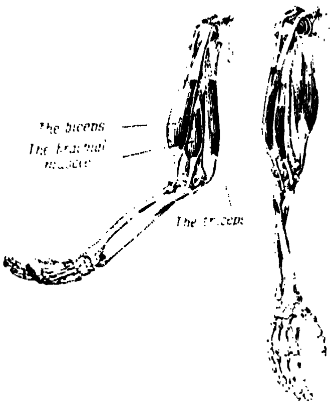


Fig. 34. Diagram of the alternating contraction and relaxation of antagonistic muscles.

The simultaneous contraction of the antagonistic muscles—for example, the brachial muscle (which bends the arm at the elbow) and the triceps (which straightens out the arm) may not produce movements, but, as the result of such a contraction, the joint is fixed firmly in a definite position.

Problem. 1. Examine the movable articulation of the skull with the spinal column (Fig. 35); find the point of support, the point of the application of power (the place where the muscle is attached) and the point of the application of resistance (on the line of the centre of gravity of the head); using the diagram in the upper part of the figure, determine the type of lever for this case.

2. In the same way analyze the action of the gastrocnemic muscle on the ankle joint when you stand on tiptoe (Fig. 36).

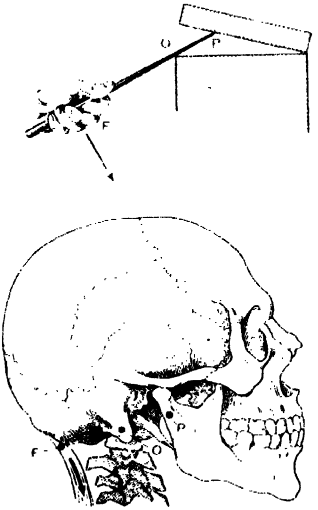


Fig. 35. Diagram of the action of the occipital muscles supporting the head.

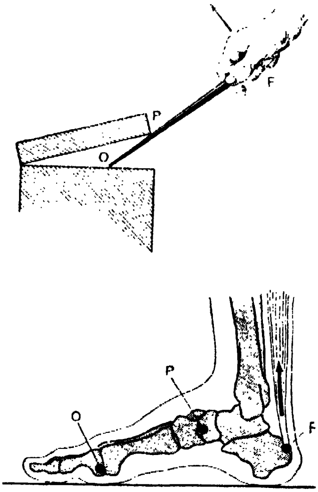


Fig. 36. Diagram of the action of the gastrocnemic muscle at the ankle joint.

O — point of support: *F* — point of the application of power (point where the muscle is attached); *P* — point that bears the resistance. At the top is the diagram of a lid raised with a stick; the position of points *O*, *F* and *P* are exactly the same.

3. Make a similar analysis in relation to the bending of the arm at the elbow (Fig. 37); explain why the lever, illustrated in the left part of the figure (the so-called lever of the third order) is rarely used in technics.

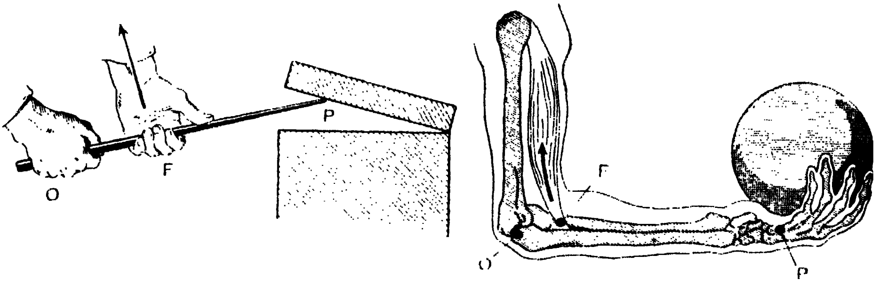


Fig. 37. Diagram of the arm bent at the elbow. The denotations are the same as in fig. 35 and 36.

15. The principal groups of skeletal muscles

The body of a human being has more than 600 skeletal muscles (Fig. 38 and 39). They may be divided into several main groups, using as a basis for this division their participation in the various movements of the body.

The muscles of the head. The muscles of the head consist of the masticatory muscles and of the muscles that produce facial expressions. The contraction of the *masticatory* muscles produces movement in the lower jaw. *The muscles that produce facial expressions* are attached to the skin by one and sometimes by both of their ends. When these muscles contract, separate parts of the skin are shifted from one place to another, thus producing the various expressions of the face. *The circular muscles of the eyes* and *of the mouth,* the contractions of which cause the compression of the eyelids and of the lips, are muscle rings that lie under the skin.

The muscles of the trunk of the body. The muscles of the trunk of the body consist of the muscles of the thorax, the stomach and the back.

The muscles of the thorax, located between the ribs, together with some other muscles, raise and lower the thorax; these are the *respiratory* muscles. They will be discussed later when the respiratory organs are studied.

The numerous muscles of the back are arranged along the spinal column; most of them are attached to the projections of the vertebrae. Some of them serve to straighten out the spinal column and to bend it backward, others serve to turn it, while still others bend it to one side. Some of the muscles of the back are attached by one of their ends to the spinal column and by

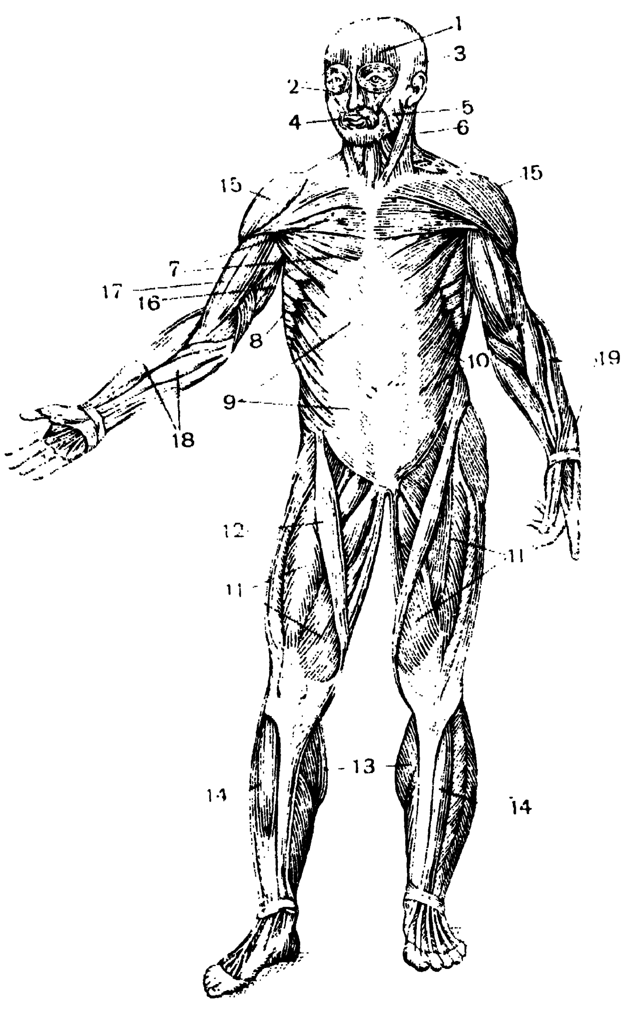


Fig. 38. Front view of the muscles of a human being:

1 — frontal muscle that produces vertical folds in the skin of the forehead; *2 — orbicular muscle* of the eye, which closes the eye; *3 — temporal muscle; 4 — orbicular muscle of the mouth,* which closes the mouth; *5 — masticatory muscle* (which, with other muscles, produces the masticatory movements); *6 — sternocleidomastoid muscles* (a pair of muscles that, in contracting, bow the head forward; one, acting by itself, turns the head to one side, bending it in the direction of the contracted muscle); *7 — large pectoral muscle* (which lowers the arm, bringing it forward; this muscle raises the thorax when the arm is in a state of rest); *8 — serrated muscle* (which raises the thorax when one inhales deeply); *9 — erect abdominal muscle* (which bends the trunk of the body forward and lowers the thorax); *10 — oblique abdominal muscle* (bends the trunk of the body forward and turns it to one side); *11 — quadriceps* (four-headed extensor of the thigh); *12 — sartorial muscle* (bends the leg at the knee and turns it inward); *13 — gastrocnemic muscle* (bends the ankle joint, i. e., it lowers the front part of the foot and raises the back part, thus enabling a person to stand on tiptoe); *14 — anterior tibial muscle* (straightens out the ankle joint); *15 — deltoid muscle* (raises the arm); *16 — triceps* (three-headed muscle, which straightens out the arm at the elbow); *17 — biceps* (two-headed muscle, which bends the arm at the elbow); *18 — flexors of the wrist and fingers; 19 — extensors of the wrist and fingers.*

their other end to the ribs; such muscles take part in the movements of the thorax.

The movement of the trunk of the body in bending forward is produced chiefly by the muscles of the stomach. A very tough tendinous cord runs along the central line of the stomach from the top to the bottom. On either side of the tendinous cord are located the right and the left *erect abdominal muscles*, which are attached at the top to the lower edge of the thorax, and at the bottom to the point of the articulation of the pelvic bones. *The outer* and *inner oblique muscles of the stomach* are located along both sides of the erect abdominal muscles. When the right and left oblique muscles contract simultaneously, they bend the trunk of the body forward. The contraction of any one of the oblique muscles separately serves to turn the trunk of the body to the side. Besides this, the abdominal muscles, in contracting, press against the abdominal cavity and pull the thorax downward.

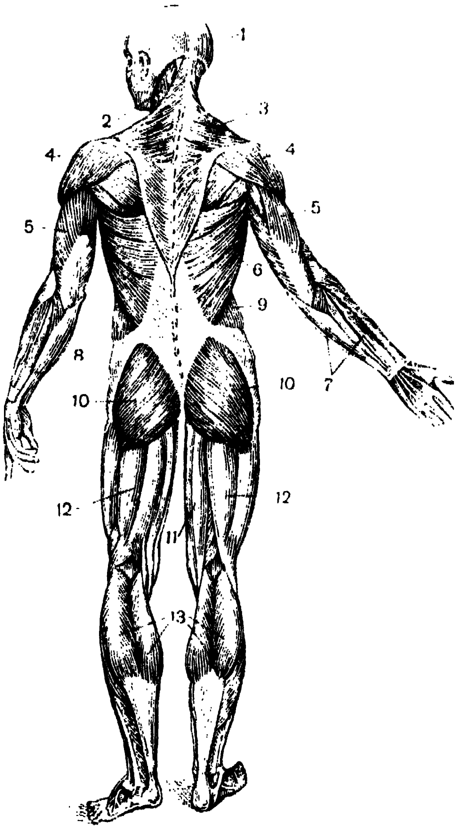


Fig. 39. Back view of the muscles of a human being:

1 — *occipital muscle*; 2 — *muscles of the neck* (that produce movements of the head); 3 — *trapezoidal muscle* (that draws the scapula toward the spinal column); 4 — *deltoid muscle*; 5 — *triceps of the upper arm*; 6 — *wide muscle of the back* (that turns the arm inward and carries it back); 7 — *extensors of the wrist and fingers*; 8 — *flexors of the wrist and fingers*; 9 — *oblique muscle of the stomach*; 10 — *large gluteal muscle* (turns the thigh outward); 11 — *semi-tendinous muscle* (straightens out the leg at the joint of the pelvis and thigh; it bends the leg at the knee joint and turns the leg inward); 12 — *biceps of the thigh* (bends the leg at the knee); 13 — *gastrocnemic muscle.*

The muscles of the neck. The muscles situated in the neck throw the head back, bow the head and turn it; some of the muscles draw the lower jaw down. When the head is held in an immovable position, the *sternocleidomastoid* muscle, and some other muscles of the neck, raise the thorax.

A whole group of neck muscles takes part in the movements of the hyoid bone. This bone is connected, at the top, with the tongue, and at its base, with the larynx. The muscles attached to the hyoid bone are connected, by their other end, with one of the adjacent bones (the temporal bone, the lower jaw, the sternum). The contraction of these muscles, which sets the hyoid bone into motion, changes the position of the tongue and of the larynx during the act of swallowing, or when different sounds are uttered.

The muscles of the extremities. The great number of muscles of the extremities, the shoulder girdle and the pelvis take part in the various movements of the arms and legs. Besides the flexors and extensors, there are other muscles of the extremities, which, in contracting, produce rotating movements (for example, the turning of the forearm in such a way as to make the palm of the hand face forward or backward). The contraction of other muscles produces the movements of the extremities: the putting forward of the arms and legs, and their withdrawal.

Many muscles (*the wide muscle of the back, the large pectoral muscle of the chest,* and others), which are attached by one of their ends to the extremities and by their other end to the trunk of the body, take part in the movements of the arms and legs.

Problem. Using the figures in the text-book, find the biceps and the triceps in the upper part of the arm of your own body. Determine which of these muscles is in a state of tension, and which is in a state of relaxation, when you bend your arm at the elbow, and then when you straighten out the arm (make the movements without exerting any strain).

Give other examples of the work of the antagonistic muscles.

16. The work of the muscles

The importance of the power of a muscle, and of the size of its contractions. The work of a muscle depends upon the power of the muscle and upon the size of its contractions. The thicker the muscle, and the greater the number of fibres that compose it, the stronger the muscle and the greater the amount of work it can perform. The size of the contraction of a muscle — that is, the degree to which it is shortened — depends upon the length of the muscle fibres: the longer the muscle fibres, the more they will shorten.

The fibres of some muscles (the gastrocnemic muscles and others) are arranged, not lengthwise, but slantwise, like the barbs of a bird's feather. These muscles contain a greater number of fibres than longitudinal muscles of the same thickness; therefore, the power of their contractions can be twice or three times as great as that of muscles with longitudinal fibres. However, the size of their contractions is very small (they shorten very little), because of the oblique arrangement of their muscle fibres (Fig. 40).

Nerve regulation of the work of the muscles. The cause of muscle contraction is the stream of impulses coming from the nervous system. Upon the nervous system also depends *the tone* of the muscles, that is, the state of the tension peculiar to muscles even when they are in a state of rest. The tone, as well as the work of the muscles, depends, to a very great extent, upon the processes of metabolism going on in them; the processes of metabolism are likewise regulated by the nervous system, both directly and indirectly, by means of the changes in the blood supply of the muscle, that is, by means of the constriction and dilation of its blood vessels. Thus, the muscles are subjected to a threefold nervous control.

In the human being the work of the muscles is entirely under the control of the higher division of the nervous system — the cortex of the cerebral hemispheres. An injury to the so-called *motor area of the cortex* brings about paralysis of movement. If one of the hemispheres is injured, then movement also ceases, but only in one (the opposite) half of the body.

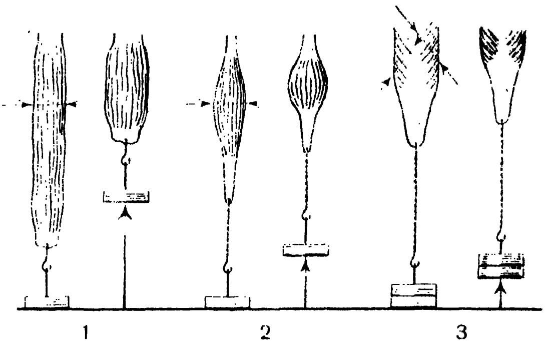


Fig. 40. Diagram showing how the length and power of muscle contractions depend upon their structure:

1 — muscles with long, parallel fibres; *2* — muscles with short, parallel fibres; *3* — muscles with oblique fibres (such a muscle has twice as many fibres as the others).

Through the cortex the various changes that go on, both in the surrounding medium and in the organism itself, may affect the working capacity of the muscles. When a person is fatigued, in low spirits, or in a bad mood, his movements become sluggish, and there is little coordination in them, while the muscle tone is lowered — the figure sags, the person becomes round-shouldered; as a result of the weakened tone of the facial muscles of expression, the face assumes a depressed and dejected expression. On the other hand, when a person is cheerful, he works willingly and enthusiastically, his movements are exact, quick and coordinated, and the muscle tone rises — his figure straightens out, and his face assumes an energetic expression.

The importance of rhythm in the work of a muscle. As in walking or in running, so also in the movements that produce work (the chopping of wood, working with a saw, writing), the various groups of muscles contract alternately; furthermore, the contraction and the relaxation of the separate muscles alternate regularly. Such rhythm of movement is of great importance.

When a muscle is working, some of the substance which enters into the composition of its muscle fibre begins to decompose. The muscle rests in the intervals between the separate contractions; thus, the state in which it was before the contraction took place is quickly restored, and the working capacity of the muscle is complete again.

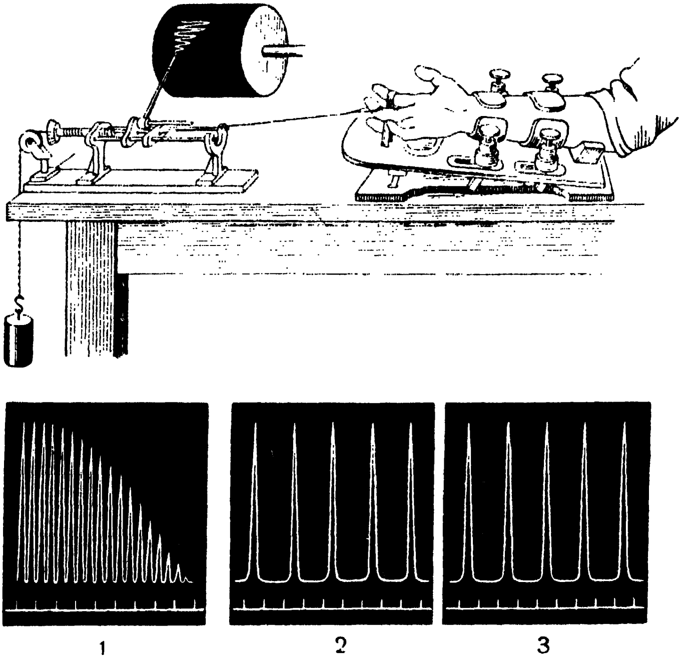


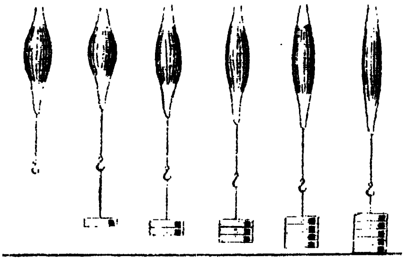
Fig. 41. Upper figure: apparatus for registering the work of muscles. Lower figure: record of the movements of the finger on the kymograph:

1 — when there is a maximum frequency of movements: *2* and *3* — when the movements are less frequent (*2* — at the beginning; *3* — 10 minutes later).

However, if some muscle, or group of muscles, keeps on working incessantly, fatigue quickly sets in. Everyone knows how difficult it is to hold even a small weight in the hand when the arm is raised and outstretched. The muscles of the arm become tired very soon and the arm drops, in spite of all one's efforts to maintain it in position. Prolonged contraction of a muscle may result in the complete loss of its power of action.

We may observe the fatigue of a muscle and the restoration of its working capacity after rest by using a special apparatus. An apparatus of this kind is illustrated in fig. 41. It is designed for the study of the work and fatigue of the muscles which bend the fingers of the hand. Each time the finger is bent, the muscles perform work and the weight suspended from the pulley rises. A pencil, fixed immovably in the apparatus, makes a drawing on the paper of *the curve of the muscle contractions.* A special recording pen, the sharpened point of which moves along the blackened surface of a moving drum — the kymograph — is often used instead of a pencil for the recording of such a curve. The recording obtained in this way is illustrated in the same figure.

As the recording shows, rapid fatigue of the muscles sets in when the finger movements are frequent: the height of the contraction is gradually·decreased, and after some time the weight ceases to rise. When the movements occur less frequently, the muscles have time to rest after each contraction and, as a result, there are no signs whatever of fatigue even after 10 minutes of work.



Load (in grams)	0	100	200	300	400	500
Height of the elevation (in mm)	6	7	5	3	1½	0
Work (in gram millimetres)	0	700	1000	900	600	0

Fig. 42. Diagram showing how the work of a muscle depends upon the magnitude of the load.

The significance of the load. The power of the movements, and not only their frequency or rate, is of great importance in work. Figure 42 shows the results of the work of a muscle with a rate of movement that is constant, but with loads that vary in magnitude. The amount of work performed in raising the various loads is calculated in gram-millimetres.[1]

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[1] For such calculation, it is necessary to measure the height of each separate elevation of the load; adding up all the heights, we get the total height of the elevation of the load resulting from all the movements of the finger; multiplying the load in grams by the height of the elevation in millimetres, we get the total amount of work of the muscles, done by all the bendings of the finger, expressed in gram-millimetres.

Experiment shows that a change in the amount of the work done depends upon a change in the magnitude of the load; if the load is not large, not much work is done; if the load is increased, the amount of work performed gradually increases, and reaches the maximum, that is, the greatest *amount, and then begins to decrease*; finally, the load may become so great that the muscle cannot cope with it, and then the amount of work performed drops to zero.

In performing different types of muscle work, we may change the power and speed of the movements according to our desire. However, if we do this, the amount of work performed will also change. Too great a load, or too great a frequency of the rate, will result in the rapid fatigue of the working muscles and in a sharp reduction of the amount of work done. The rate and load for each kind of physical work may be so selected that the greatest productivity can be achieved with the least amount of fatigue.

To many strong and physically healthy people, walking at the rate of 5 or $5^1/_2$ *km* per hour is most favourable; that is, the greatest amount of work is produced with the least amount of fatigue. When walking with a load, or when climbing a mountain, the optimal, that is, the best rate of walking, is considerably lower.

By using an apparatus for registering the work of the muscles, Setchenov, the great Russian scientist, determined the magnitude of the load at which bending the finger at the rate of 20 times per minute did not cause any fatigue whatever. The raising of this load by the finger continued without interruption for four hours running. A larger load or a more rapid rate of work brought about fatigue in a short time.

The effect of the work of the muscles on the organism. Muscles that perform a sufficient amount of work increase in size, and become thicker and stronger.

The more a muscle works, the greater is its need for oxygen and nutritive material. Thus, muscle work not only strengthens the working muscles themselves, but intensifies the activity of the organs of respiration and circulation and, in that way, exercises the muscles of the thorax and the heart muscle. More than that, energetic work of the muscles increases the appetite, produces a feeling of general vigour and improves the mood; in this way, the vital activity of the whole organism is increased.

It is clear from all this that physical labour, athletics, sport, active games, gymnastics, walking tours are of vast importance in strengthening the bony-muscular system and, through the bony-muscular system, in strengthening the whole human organism.

We know that I. P. Pavlov was weak and sickly during his childhood, and that he improved his health by doing gymnastics and physical labour systematically. In 1936, in his greeting to the conference of the miners of the Donetz Basin, Pavlov wrote: "All my life I have loved and still love mental and physical work, and, I dare say, even prefer the latter."

Problem. Take a heavy object (for example, a weight) and see how long you can hold it in your hand with the arm outstretched. Rest a while and then, with the same object in your hand, see how long you can raise and lower your arm rhythmically.

REVIEW QUESTIONS

1. What are the properties of a bone, and upon what do they depend?
2. How does a bone grow in length?
3. Give some examples of fixed and of various types of movable articulations of the bones.
4. Enumerate the basic rules for rendering first aid in cases of dislocations and fractures.
5. Enumerate the peculiarities in the structure of the human skeleton, and show how these peculiarities are due to the erect posture of man.
6. What are the differences in structure and properties between the smooth and the striated muscles?
7. What is muscle tone and how is it maintained?
8. What is the importance of rhythm in work?
9. Show how a change in the work of the muscles depends upon a change in the magnitude of the load.
10. How does the activity of the muscles affect the organism?

III. THE ORGANS OF CIRCULATION

17. The significance of the circulation of the blood

Tissue fluid. Tissue fluid, or *tissue lymph,* constitutes about 50 per cent of the weight of the body, and fills up all the intercellular interstices (spaces). This fluid, which is in direct contact with the cells, is *the internal medium of the organism.*

Tissue fluid is a necessary condition for the existence of the cells and of the tissues: the cells and tissues are constantly absorbing oxygen and nutritive material from it, and are just as constantly giving up to it carbonic acid and other products of metabolism.

Any decrease in the tissue fluid of those substances necessary for the cell or, on the contrary, the accumulation of waste products, destroys the normal activity of the cells. In order that metabolism, and, together with metabolism, all the other life processes should be able to proceed normally, the composition of the tissue fluid must be kept constant. In other words, the materials needed by the cells must be continually renewed in the tissue fluid, while the waste products must be eliminated from it.

The movement of the blood in a circuit. Continuity in the composition of the tissue fluid is provided for by the constant movement of the blood through the blood vessels.

In vertebrates, including man, the blood vessels form a closed circuit. The movement of the blood in a circuit through the blood vessels is called *circulation*. In the human being, as in all mammals, there are two circuits of the circulatory system — the large, or systemic, circuit and the small, or pulmonary, circuit (see coloured plate II).

The large, or systemic, circuit of the circulatory system. The systemic circuit of the circulatory system begins at *the aorta,* which leaves *the left ventricle* of the heart, rises upward, and then, forming *an arc,* proceeds downward along the spinal column.

Large *arteries* extend from the arc of the aorta and carry blood to the head and to the upper extremities.

Branchings, issuing from the aorta below the arc, pass to the muscles of the trunk of the body and to the abdominal viscera. On a level with the lumbar vertebrae, the aorta divides into two large arteries, which supply blood to the lower extremities.

The large arteries branch out over and over again, forming smaller and smaller vessels, which carry blood to all parts of the body. The minutest arteries break up at their ends into a dense system of very fine hair-like blood vessels, called *capillaries.* They are so fine that the area of a cross-section of one of them is, on the average, not more than one eight-hundred-thousandth of a square millimetre; in other words, they are much finer than a human hair. A capillary is also very insignificant in length — less than one millimetre. The impossibility of making an exact calculation of all the capillaries of the body is clear. However, it is supposed that the total number of capillaries in the body is about a trillion.

The capillaries combine with one another to form *the veins.* The small veins combine to form larger and larger veins. The blood from all parts of the body flows through the two largest veins — *the upper,* or *superior, vena cava* and *the lower,* or *inferior, vena cava,* and returns to the heart, to its *right auricle.* Here the systemic circuit of the circulatory system ends.

The small, or pulmonary, circuit of the circulatory system. The blood from *the right ventricle* passes through *the pulmonary artery* and its branches, and flows into the right and left lungs. In the lungs, the exceedingly minute arteries branch out and form capillaries, which unite with one another to form the veins. As in the case of the systemic circuit of the circulatory system, these small veins keep on combining to form larger and larger veins until, finally, the blood is propelled to *the left auricle* of the heart through four *pulmonary veins.* The passage of the blood from the right ventricle to the left auricle is called the small, or pulmonary, circuit of the circulatory system.

The significance of the permeability of capillaries. The blood, which is enclosed in blood vessels, does not come in direct contact with the cells of the organs and of the tissues. However, through the thin walls of the capillaries (the wall of a capillary consists of one layer of flat cells), oxygen and nutritive material force their way out of the blood into the tissue fluid, while carbonic acid and other substances, formed in the cells, pass into the blood.

Not all the substances of the blood pass through the walls of the capillaries with equal ease, for the capillaries are not equally permeable to all substances. That is why the composition of tissue fluid is different from that of blood; tissue fluid, for instance, contains practically no proteins, while blood contains almost 7% of proteins.

Arterial and venous blood. The blood which flows through the arteries of the systemic circuit of the circulatory system is saturated with oxygen. Such blood is called arterial blood. The blood in the capillaries loses much of its oxygen and becomes rich in carbonic acid. Blood that contains little oxygen and much carbonic acid is called venous blood. The venous blood travels along the veins of the systemic circuit of the circulatory system and flows into the right half of the heart; from there, it passes into the arteries of the pulmonary circuit.

In the arteries of the pulmonary circuit there is venous blood. The venous blood in the capillaries of the lungs gives up its excess of carbonic acid and takes in oxygen. Arterial blood flows through the veins of the pulmonary circuit of the circulatory system and passes to the heart.

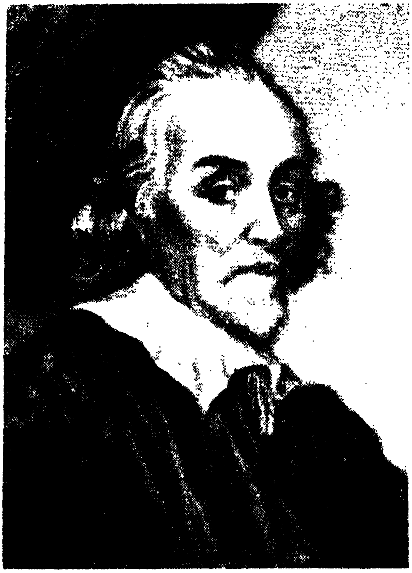
The role of blood circulation in metabolism. The vast importance of the circulation of the blood is now clear. The constancy of the composition of the tissue fluid is maintained by the unceasing movement of the blood: the blood carries oxygen and nutritive material to the tissue fluid, and removes from it carbonic acid and other products of metabolism.

The products of metabolism that accumulate in the blood are constantly being discharged into the outer medium: carbonic acid is eliminated through the lungs, and the greater part of other substances — through the kidneys. Ever fresh quantities of nutritive material and oxygen from the external environment are continually passing into the blood: nutritive material — through the intestines, and oxygen — through the lungs.

Circulation and the unity cf the organism. The importance of the circulatory system is not limited to its participation in the interchange of products between the tissues of the organism and the external environment. The circulation of the blood also provides for *chemical interaction* between the organs of the body. Due to the fact that the structure and functions of the separate organs are different, the products of their metabolism are likewise different. Each organ gives up to the blood certain substances which influence the activity of other organs of the body.

When the muscles are at work, substances are formed in them which get into the blood and affect the work of many organs of the body. These substances, in particular, intensify the secretion of the digestive juices, and thus improve the appetite. On the other hand, too great an accumulation of these substances in the blood hinders the secretion of the juices, and thus spoils the appetite. Certain other substances, secreted in the wall of the intestinal canal, act by means of the blood on the various organs and on the muscles. This interchange of products, this chemical interrelation between the organs of the body, helps to provide for the unity and unceasing activity of the organism as a whole.

From the history of the discovery of blood circulation. The foundation of scientific, experimental physiology was laid by the discovery of the circulation of the blood. In 1628, Harvey, an English physician, published a book in which the movement of the blood in a circuit was described for the first time. In the preface of the book Harvey called upon scientists "to learn and to teach, not from books, but from the objects of experimentation; not from the dogmas of learning, but in the workshop of nature." At the time Harvey lived, not only theologists, but men of science affirmed that "the movement of the heart can be known only to the one god." Harvey, basing himself on experiment, proved that the heart, pumping the blood, forces it to move in a circle; in this way, a blow was dealt to the vague theories prevailing at that time about the immortality of the soul and about the heart as the source of living flame. Harvey's discovery created a real revolution in the study of the human organism.



William Harvey

Hot disputes arose round Harvey's theory of blood circulation. Religious and reactionary people attacked Harvey for denying the "infallible" authority of antiquity, and also for denying the existence of "divine wisdom." Molière, a famous French writer of the 17th century, in his dramas, "The Imaginary Invalid" and "Monsieur de Pourceaugnac," satirized the Parisian anatomist Riolan and other opponents of Harvey, who refused to recognize anything new.

The disputes about the theory of blood circulation, — in other words, the disputes between the advocates of the new, true science and the adherents of old ideas, ended only in the second half of the 17th century, when scientists first saw under the microscope the capillaries that unite the arteries with the veins.

Problem. Make a diagram of the circulatory system and mark with arrows the direction of the movement of the blood.

18. The structure of the heart

Location of the heart. The heart is located in the thoracic cavity, approximately on the central line of the body, behind the sternum and a little to the left of it. The upper part of the heart, from which the blood vessels issue, is called *the base*, and the lower, somewhat tapering part is called *the apex* (Fig. 43).

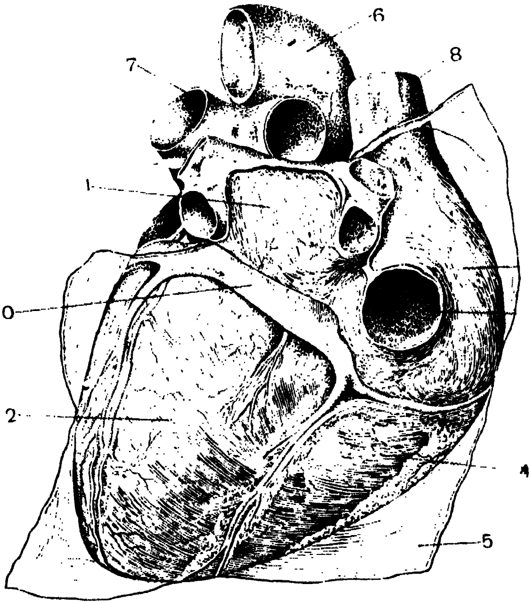


Fig. 43. Heart (back view):

1 — left auricle with the pulmonary veins that enter it; *2* — left ventricle; *3* — right auricle; *4* — right ventricle; *5* — pericardium cut open with its edges turned outwards; *6* — aorta; *7* — pulmonary artery; *8* — superior vena cava; *9* — inferior vena cava; *10* — coronary blood vessels of the heart.

The main mass of the wall of the heart is composed of *the heart muscle*, the outer and inner surfaces of which are covered with a smooth membrane. The heart is completely surrounded by a compact membraneous sac, *the pericardium*. Between the outer surface of the heart and the pericardium there is a closed cavity, the walls of which are always moist; this protects the heart from friction, and at the same time renders its work much easier.

The heart muscle. The heart muscle differs from other muscles of the internal organs in that it is cross-striated. The fibres of the heart muscle are connected with one another with the help of the projections of the protoplasm. By means of such little "bridges" the protoplasm of one fibre passes directly into the protoplasm of the adjoining fibres.

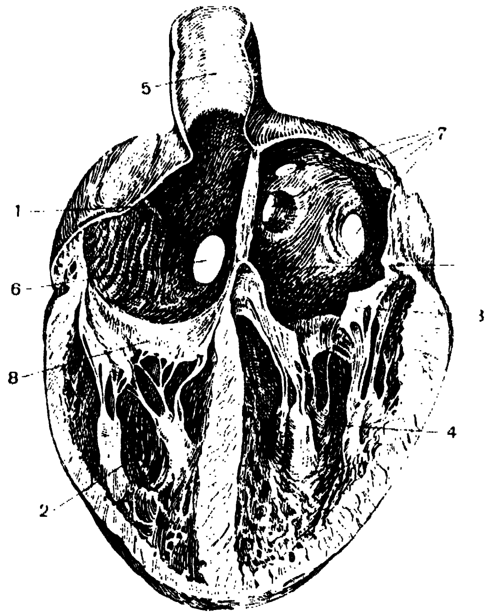


Fig. 44. Heart (cut open):

1 — right auricle; *2* — right ventricle; *3* — left auricle; *4* — left ventricle; *5* — superior vena cava; *6* — calibre of the inferior vena cava; *7* — calibres of the pulmonary veins; *8* — valves between the auricles and the ventricles.

If the muscle fibre is stimulated (by an electric current, for instance), a wave of contraction begins at the point of stimulation and quickly spreads along the whole fibre. In the skeletal muscles, the wave of contraction travels only along those fibres that have been stimulated. In the heart muscle, the wave of contraction spreads, by means of the little "bridges" of protoplasm, from one fibre to another and is rapidly communicated to the whole muscle.

No matter in what part of the heart muscle a wave of contraction arises, it immediately spreads throughout the whole muscle.

A remarkable property of the heart muscle is its incapacity to produce a tetanic contraction. Any skeletal muscle may remain in a state of continuous contraction for many seconds and even minutes. The heart, however, always passes into a state of relaxation after each contraction (a contraction of the heart lasts only one-tenth part of a second).

This may be explained as follows: if another stimulus is applied to any muscle at the moment a wave of excitation begins, no new wave of excitation is aroused: the muscle becomes, as it were, insensitive to any new irritation. In the skeletal muscle, the power to produce a new wave of excitation is restored long before the contraction terminates: a contraction lasts 0,1 of a second, while the period of inexcitability lasts only several thousandths of a second. For that reason, in the skeletal muscle, frequent waves of excitation may arise that maintain continuous contraction.

The heart muscle restores the power to produce a new wave of excitation much later: it becomes sensitive to irritation only at the moment of relaxation, and then it is able to contract again.

The auricles and ventricles. A compact partition divides the heart into two halves — the right and the left (Fig. 44). Each of these halves consists of two communicating chambers — a thin-walled *auricle* and a fleshy *ventricle.*

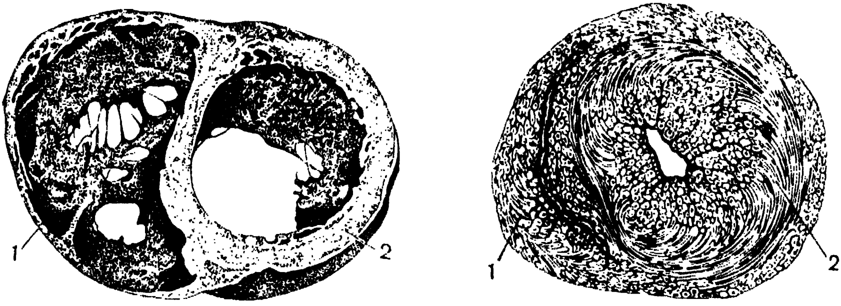


Fig. 45. Cross-section of the ventricles of the heart:
left — in a state of relaxation; right — in a state of contraction:

1 — right ventricle; *2* — left ventricle.

Two large veins pass into the right auricle: *the superior vena cava,* which receives blood from the upper part of the body, and *the inferior vena cava,* which takes up blood from the lower part of the body. Besides these, a vein which carries the blood from the heart muscle itself passes into the right auricle. Four *pulmonary veins,* two from each lung, pass into the left auricle.

The ventricles occupy the greater part of the heart. *The pulmonary artery* issues from the right ventricle, while the main artery of the body — *the aorta* — issues from the left ventricle.

The difference in the thickness of the walls of the auricles and ventricles can be accounted for by the difference in the work that they perform. The muscle of the auricle pushes blood only into the ventricle. The contracting muscle of the ventricle drives the blood through a long and branching network of blood vessels.

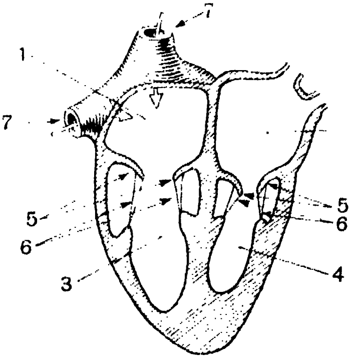


Fig. 46. Diagram of the folding valves between the auricles and ventricles:

1 — right auricle; *2* — left auricle; *3* — right ventricle; *4* — left ventricle; *5* — valves; *6* — tendinous threads which prevent the valves from bending back to the auricles; *7* — superior and inferior venae cavae.

The work of the left ventricle is especially great, because it propels the blood through the systemic circuit of the circulatory system and, consequently, through the capillaries of all the organs and tissues of the body, except the lungs. As a result, the muscle of the left ventricle is very much thicker than that of the right ventricle (Fig. 45).

The valves of the heart. *Folding valves* (Fig. 46), which have the shape of plates and consist of thick connective tissue, separate the auricles from the ventricles. The valve in the right half of the heart consists of three such plates, or flaps; the valve in the left half of the heart has two. When the flaps close, the valve shuts tight the passage between the auricle and the ventricle. Tendinous threads extend from the bottom of the muscle protuberances of the inner surface of the ventricle to the flaps of the valve.

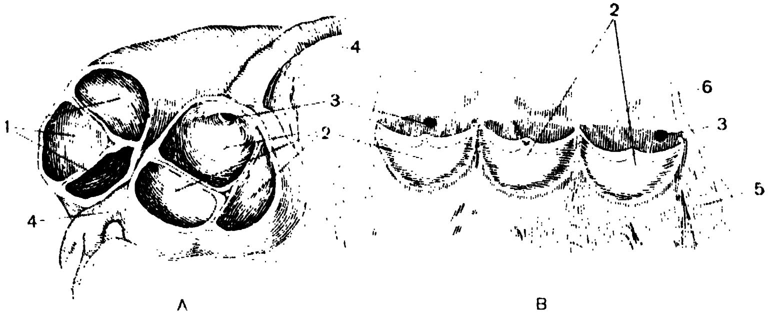


Fig. 47. Semi-lunar valves:
A — top view; *B* — side view; cross-section:

1 — valve between the right ventricle and the pulmonary artery; *2* — valve between the left ventricle and the aorta; *3* — opening of the coronary artery; *4* — coronary arteries which supply the heart muscle with blood; *5* — wall of the ventricle; *6* — wall of the aorta.

The folding valve can open in one direction only — that of the ventricle. When the ventricles relax, the valves open and the blood pours freely from the auricle into the ventricle. When the ventricles contract, the blood cannot flow back into the auricle, because the flaps of the valve close up under the pressure of the blood, and the tautly stretched tendinous threads prevent the flaps from turning back in the direction of the auricles.

The blood from the ventricles flows into the arteries. The movement of the blood in the opposite direction is prevented by the *semi-lunar valves,* which, in the shape of little pockets, are located in the aorta and in the pulmonary artery at the very exit of these vessels from the heart (Fig. 47). When there is a flow of blood from the ventricles to the arteries, the little pockets of the valves are pressed to the walls of the vessels, thus allowing the blood to pass freely. When the blood flows back, it fills up the little pockets of the valves — the little pockets bulge out, completely covering up the calibre of the vessel, and thus prevent the arterial blood from flowing back into the ventricles.

Problem. Make a drawing of the structure of the heart and show, by means of arrows, the direction in which the blood moves.

19. The work of the heart

The rhythm of the heart contractions. In order to study the work of the heart, experiments are usually performed on animals. After an anaesthetic and artificial respiration have been applied, the thorax is cut open, and the heart exposed; then one of the small levers of the apparatus is connected with the auricle and the other with the ventricle of the heart; as a result, two wavy lines will be recorded on the kymograph: one illustrates the contractions of the auricles, and the other — the contractions of the ventricles (Fig. 48).

The first thing that we notice in watching the work of the heart is the regular *periodicity* (the rhythm) of its contractions. Each fresh contraction follows the preceding one after a strictly definite period of time. The heart of an adult who does not perform any strenuous work contracts approximately 60 to 80 times a minute. The heart of a child, especially of a little child, contracts more often.

The contraction begins in the right auricle at the points where the superior and inferior venae cavae enter it; then it is quickly communicated to the auricles and passes on to the ventricles, both of which contract simultaneously (Fig. 49). The contraction of the auricles lasts a trifle over 0,1 of a second; during that time the ventricles are in a state of relaxation. Immediately following the contraction of the auricles, both ventricles begin to contract, each contraction lasting about 0,3—0,4 of a second; while the ventricles are contracting, the auricles remain relaxed. After the contraction of the ventricles, the whole heart relaxes. This moment of relaxation of the whole heart is called *a pause*. When the pause takes place, the heart fills up with blood flowing from the veins. The length of the pause depends, to a great extent, on the frequency of the heart contractions; when there are 60 to 80 contractions a minute, the pause lasts about 0,4 of a second.

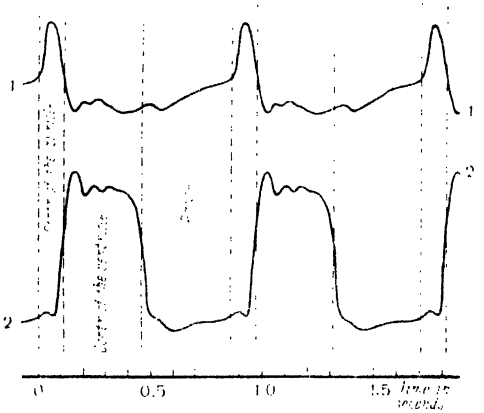


Fig. 48. Separate record of the contraction of the auricles *(1)* and ventricles *(2)*. At the bottom: scale of the time (in tenths of a second).

The independent work of the heart. The skeletal muscles contract when they receive impulses coming from the central nervous system. If these muscles are cut out of the body, they cannot contract by themselves. The heart muscle, however, acts in quite a different way; waves of excitation may arise in it independently.

The heart of a frog continues to contract rhythmically even after it has been separated from the body and put into a small glass containing a physiological solution.[1]

The heart of a mammal also goes on contracting independently after it has been cut out of the body. For that purpose, a specially prepared nutritive liquid, taking the place of the blood, is saturated with oxygen beforehand, then heated to a definite temperature and injected through the blood vessels of the heart muscle.

Sometimes it is also possible to force the human heart to contract after it has been separated from the organism. Kulyabko, a Russian scientist, "revived" the heart of an infant 20 hours after the death of the infant.

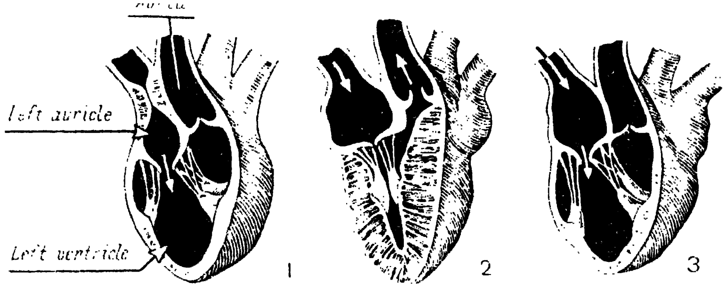


Fig. 49. Diagram showing the different phases in heart rhythm:
1 — beginning of the contraction of the auricles; 2 — contraction of the ventricles; 3 — pause.

Under normal conditions, the section of the heart that is most easily excited is the point where the superior and inferior venae cavae enter the heart. This explains why it is at this point, namely, that the heart contractions begin.

The work of the heart muscle. The heart muscle performs a vast amount of work. Each ventricle of the human heart, in contracting, pours into the arterial stream approximately 60 to 80 cubic centimetres of blood. In one contraction the left ventricle performs, on the average, work equal to 0,08 or 0,09 kilogram-metres. The right ventricle, which drives the blood only through the lungs, performs less work, not exceeding 0,02 kilogram-metres. We may say that both ventricles of the heart fulfil, at each contraction, work equal to about 0,1 kilogram-metre.

In one minute the heart performs work equal to 6 or 8 *kgm.* In the course of one day, the heart, pumping thousands of litres of blood, performs a tremendous amount of work that exceeds 10 000 *kgm*. Such work is performed by a crane that lifts a two-ton load to a height of 5 metres.

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[1] A physiological solution is a solution of sodium chloride. Due to the fact that the composition of the blood of a frog differs from that of mammals, the physiological solutions used for these animals are different: for frogs 0,6% of sodium chloride is taken, while for mammals it is 0,9%. Sometimes a more complex solution is used which contains a small quantity of other salts, and also grape sugar.

The reason for the indefatigability of the heart. The heart, which weighs only 300 grams, performs a vast amount of work during a person's life; moreover, it does not cease its work for even one moment. How does it manage to do such an amount of work that is seemingly beyond its strength? The reason for the indefatigability of the heart muscle lies in the rhythmic motions of its work — in the regular alternation of contraction and relaxation.

The skeletal muscles can also work for a long time without manifesting fatigue, if there are alternate contractions of the various groups of muscles. This is exactly what happens in walking, sawing wood, working at a lathe, and in other kinds of working activity. The work of the respiratory muscles is a very good example of such indefatigable activity.

If a muscle keeps on contracting unceasingly, fatigue quickly sets in. This explains why it is impossible to stand immovable, taut like a cord, for a long time, or to hold even a small load in the hand with the arm outstretched.

The heart never stops working; nevertheless, it rests every second. If we consider that the heart contracts 75 times a minute, then each full period of contraction lasts 0,8 of a second. The contraction of the auricles takes up 0,1 of a second of this time, and the contraction of the ventricles — 0,3 of a second; the pause lasts 0,4 of a second. Thus, the ventricles rest almost twice as much as they work. The auricles rest for a still longer time. The small intervals of rest following each contraction are quite enough to put the heart muscle into a fit condition to contract again with the same power.

20. The movement of the blood and lymph through the vessels

The structure of the blood vessels. The arteries, capillaries and veins differ greatly from one another in structure (Fig. 50).

The thick wall of the large arteries contains smooth muscle fibres and a great number of tough, elastic fibres. Such a structure gives it resistability and elasticity.

Each time the heart contracts, it forces regular portions of blood into the vessels; the pressure of the blood causes the aorta and other large arteries to dilate. The arteries, by virtue of the elasticity of their walls, resist this dilation, and when the heart pause occurs, gradually press out the excess blood contained in them, thus returning to their initial state. As a result of such dilation and of the subsequent compression of the arterial wall, the flow of blood from the large arteries to the smaller ones does not cease in the intervals of time between two contractions of the heart. In other words, the movement of the blood in the blood vessels never ceases, in spite of the fact that the blood leaves the heart only at the moment the ventricles contract.

The narrower the artery, the thinner is its wall. The wall of arteries of medium size consists of a thick muscle layer and contains a comparatively small amount of elastic fibres. The wall of the very smallest arteries consists of a layer of flat cells, covered on the outside with muscle fibres arranged in a single row. Finally, the muscle fibres disappear altogether, and the arteries are then turned into capillaries consisting of one layer of thin, flat cells, through which the interchange of products between the blood and the tissue lymph takes place easily.

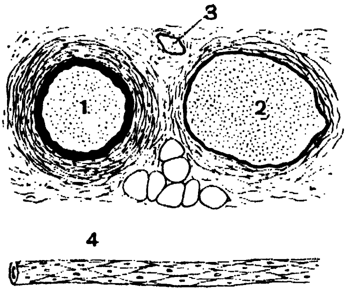

Fig. 50. Structure of the blood vessels:

cross-section of a large artery (*1*), of a large vein (*2*), of a small vein (*3*); *4* — capillary, highly magnified.

The veins have soft walls that are easily distended and as easily constricted. The wall of a vein is thinner than that of an artery: it has a poorly developed muscle layer and very few tough, elastic fibres.

The pressure of the blood in the vessels. The heart, acting like a pump, drives the blood into the aorta and into the pulmonary artery. As a result, the blood in the large arteries is subjected to great pressure, which forces the blood through the whole vascular stream.

In all parts of the vascular system, the blood flows from a point where there is greater pressure to another point where there is less pressure. In other words, as the stream of blood travels onward, the pressure keeps on diminishing, since it spends itself in pushing forward the blood. The pressure is highest in the large arteries not far from the heart. The pressure is lowest in the large veins that carry the blood to the heart.

The blood pressure diminishes unevenly along the moving stream of blood (Fig. 51). It decreases most rapidly in those parts of the vascular stream where the resistance of the blood stream is greatest. The blood passes much more easily through the wide calibre of the aorta, which has a diameter of 2 or 3 *cm* in the human being, than through the numberless small arteries which carry blood to the separate organs of our body; the small arteries, in their turn, exert much less resistance to the movement of the blood than the minutest arteries, especially the capillaries, which have a diameter of only several thousandths of a millimetre.

The blood flowing in the capillaries overcomes the exceptionally great resistance that is created by the friction of the blood against the walls of the narrow vessels. A considerable part of the driving force of the blood — in other words, a considerable part of the blood pressure — is spent in pushing the blood along this short but difficult section of the vascular road. It is here that the blood pressure diminishes more quickly than anywhere else.

The movement of the blood in the veins. The blood pressure in the small veins rises no higher than 10 *mm.* of the mercury column. In the large veins that are nearer to the heart the blood pressure is still lower. Consequently, the blood in the veins possesses little driving force; the greater part of the driving force in the blood has already been spent, chiefly in the passage of the blood through the minute arteries and capillaries. Therefore, the blood in the veins moves under less favourable conditions than in the arteries. The conditions under which the blood moves in the veins of the lower extremities are especially hard, because there the blood, rising upward, overcomes its own force of gravity.

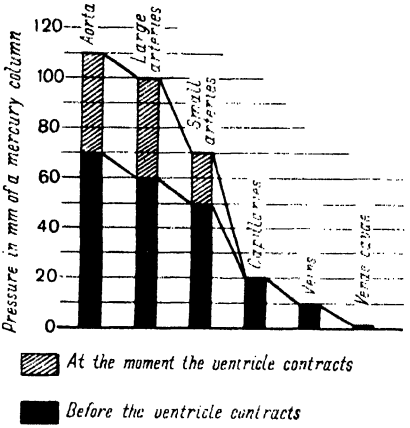

Fig. 51. Diagram showing the height of the blood pressure in various parts of the systemic circuit of the circulatory system in a boy or girl of 15 to 16 years of age.

Working motions, such as walking, physical exercises and, in general, any muscle activity, facilitate the movement of the blood in the veins, since each muscle contraction produces compression in one or another section of the venous stream. As a result of such compression, the blood is pressed onward only in the direction of the heart. It cannot move in the opposite direction (away from the heart) — this is prevented by *valves,* similar to the semi-lunar valves, situated at the origin of the aorta and of the pulmonary artery. There are such valves in all the veins (Fig. 52).

We are always making some movements, even though they may be little ones; when we are in motion, the various groups of muscles are brought into a state of contraction and press against the veins which pass through them. Thus, muscle activity is a constant and very essential auxiliary force that facilitates the movement of the blood in the veins.

Unfavourable conditions are created for the back-flow of the venous blood when the mode of life is a sedentary one and requires little motion, and also when the body is completely inactive. In such cases, the blood is often brought to a state of stagnation, which tells on the general state of health.

The pulse. The arteries may easily be felt in some parts of the body. If we feel rhythmic beats under the fingers, we may be sure that there is an artery there. The rhythmic beating of the arterial wall is called the pulse.

If an artery is pressed hard with the finger, the movement of the blood stops, but, at once, close to and immediately above the spot pressed (that is, closer to the heart), the beating of the pulse is again felt clearly. This is explained by the fact that the pulse beats do not depend on changes in the movement of the blood, but on the sudden increase of pressure in the arteries as each fresh spurt of blood passes from the ventricle to the aorta. The pulse beats are transmitted to all the arteries with a speed that is many times greater than the speed of the blood stream. By feeling the pulse we may count the number of heart beats, or pulsations.

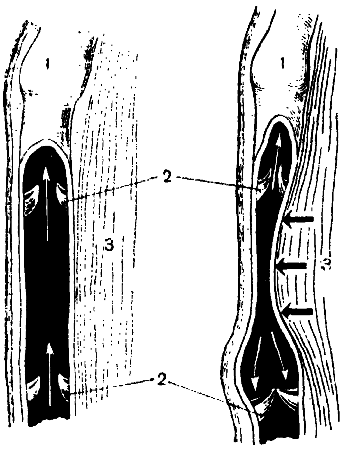

Fig. 52. Diagram showing the effect of muscle contractions on the movement of the blood in the veins. Left: a muscle in a relaxed state; right: a muscle in a contracted state:

1 — a vein: the lower part is cut open; *2* — valves of the veins; *3* — a muscle: the black arrows indicate the pressure of the contracted muscle on the vein; the white arrows indicate the movement of the blood in the vein.

The rate at which the blood moves. In the narrow course of a river the water flows very rapidly. The wider the course becomes, the slower will be the movement of the water. The rate at which the blood moves in the blood-vascular system also depends on the width of the blood stream.

The blood that passes from the heart to the aorta flows at the rate of $\frac{1}{2}$ *m* a second. How, then, does the rate of the blood stream change in its continued passage through ever smaller and smaller arteries, and then through the capillaries? The area of a cross-section of the aorta is approximately 300 *sq. mm.*, while the area of a cross-section of a capillary is one-millionth of a square millimetre. Thus it appears that the vascular course should gradually shrink in width and that the flow of the blood should increase in speed. Actually, however, the flow of the blood becomes gradually slower. This is due to the fact that the blood stream, which keeps on breaking up into an ever increasing number of branches, becomes very much wider. Each time the blood vessels branch out, they become somewhat narrower, but their number is greatly increased.

It has been calculated that the width of the capillary stream (that is, the total width of the calibres of all the capillaries in which blood flows simultaneously) is 500 and even 1000 times greater than the width of the aorta stream. Therefore, the blood in the capillaries flows from 500 to 1000 times more slowly than in the aorta, — on the average, the rate is less than 1 *mm* per second.

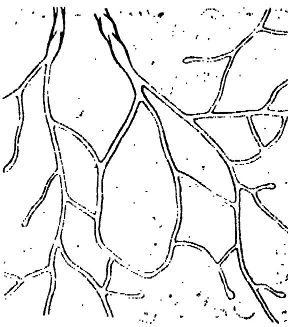

Fig. 53. Diagram showing the origin of the lymph vessels in the tissue.

As we know, oxygen and nutritive material pass from the blood in the capillaries into the tissue lymph, while carbon dioxide and other products produced in the tissues pass into the blood of the capillaries. When the flow of the blood is slow, this interchange of substances is accomplished much more easily and much more completely.

In its passage from the capillaries to the auricle, the blood course again narrows and the rate at which the blood flows increases.

The formation and movement of lymph. Water from the blood and, together with the water, most of the substances found in solution in the blood, are continually forcing their way through the thin walls of the capillaries into *the intercellular interstices* and *spaces*. In this way, tissue fluid, or tissue lymph, is constantly being formed in all the tissues of the body. The excess fluid either finds its way back into the blood, or into special vessels which are called *lymph vessels,* or *lymphatics* (Fig. 53). These usually first appear in the shape of closed little sacs and form a dense network. These first little lymph vessels unite with each other forming larger and larger vessels. Finally, the lymph, flowing in two large lymphatic streams, empties into the large veins of the systemic circuit of the circulatory system, near the heart (see coloured plate II).

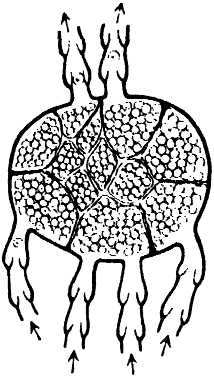

Fig. 54. Lymph node The arrows indicate the direction in which the lymph moves in the vessels, some of which lead to the node, while others lead away from it.

Lymph flows very slowly. The quantity of lymph that flows from the two lymphatic streams into the blood probably does not exceed 10 to 20 litres a day.

The conditions under which lymph moves in the lymph vessels are similar to the conditions under which the blood moves in the veins. The lymph vessels have the same kind of valves as the veins. The muscle contractions help to move the lymph forward, as they help to move the venous blood forward.

Lymph nodes. While the lymph stream keeps moving, the lymph vessels form little swellings which are called lymph nodes (Fig. 54). These consist of fine connective tissue.

The spaces between the fibres of connective tissue are filled with a great number of active cells — the white blood corpuscles, which are produced out of the connective tissue of the lymph *nodes and can multiply by cell division.*

The lymph nodes perform the role of good filters, or strainers. Here, any microbes that find their way into the blood, and spread general infection that might prove fatal to the organism, are caught and retained, and then die. The lymph nodes also retain various poisonous substances, and render them harmless.

21. The regulation of blood circulation

The work of the heart and the needs of the organism. The more any organ of our body works, the greater is its need for oxygen and nutritive material and, consequently, the greater is the amount of blood which must pass into it.

The frequency and power of the heart contractions change in exact accordance with the needs of the organism.

The very simple transition from a lying position to a sitting one, or from a sitting position to a standing one, causes an immediate change in the work of the heart. Observing oneself, it is not difficult to note that physical work, the process of digestion after a meal, agitation, sleep — all these greatly affect the character of the activity of the heart.

In what way, then, is the constant interrelation, so extremely important to the organism, established between the work of the heart and the work of the other organs of the body?

The innervation of the heart. The nervous system provides for the integrated work of the various organs. Two kinds of nerves lead to the heart: *the wandering nerves,* or *vagi,* from the brain, and *the sympathetic nerves* from the spinal cord.

The importance of these nerves is readily seen in an experiment with an animal.

If the vagi of a dog or of a rabbit are cut, the contractions of the heart become more frequent. If the vagi are stimulated by an electric current, the contractions, on the contrary, occur less often and become weaker; and if a strong current is applied to them, the contractions cease completely — the heart stops working. This experiment proves that the vagus nerve inhibits the activity of the heart, weakens its contractions and reduces the rate of the contractions.

If the sympathetic nerves are cut, the contractions of the heart become slower; when they are stimulated, the contractions become more frequent. I. P. Pavlov, at the very beginning of his scientific activity, in the eighties of the preceding century, found that the stimulation of some of the little branches of the sympathetic nerve intensified the heart contractions. Consequently, the sympathetic nerve intensifies the heart contractions, and increases their frequency.

Thus, the sympathetic nerves and the vagi exert a diametrically opposed influence on the heart (Fig. 55).

The distribution of the blood in the organs. In the organism, it very seldom happens that all parts of the body perform much work at the same time.

Numerous experiments with animals, and also with human beings, have proved that the blood vessels *dilate* when the organs are working, while the vessels of organs that are not working, or are doing little work, are *constricted.*

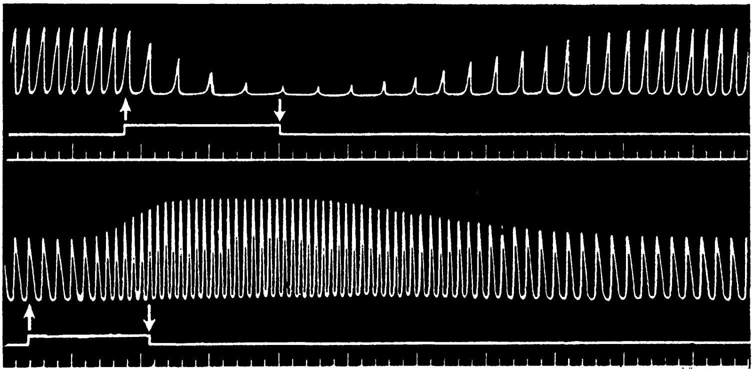

Fig. 55. Registration on the kymograph of the heart contractions of a rabbit when the nerves are stimulated: a sympathetic nerve (at the bottom) and a vagus nerve (at the top). The lower horizontal line is a scale of time; the line above the scale is a record of the nerve stimulation (the arrows indicate the beginning and the end of the stimulation).

The vast majority of the capillaries of a relaxed muscle are in a collapsed state, and it is impossible for blood to pass through them (Fig. 56). When a muscle contracts, many of the capillaries are dilated. The number of dilated capillaries and the extent to which they dilate, depend on the work performed by the muscle. The flow of blood through a muscle working intensely may be increased many dozens of times. The amount of blood in the abdominal viscera is greatly increased after a hearty meal. The vessels of the brain dilate and receive an abundant supply of blood when a mathematical problem is being solved.

The dilation of blood vessels in some parts of the body is followed by constriction in other parts. That is why the brain and the muscles receive less blood after a heavy meal, when there is a desire to lie down and no desire to do any kind of physical or mental labour.

The innervation of the blood vessels. If the sympathetic nerve on the left side of the neck of a white rabbit is cut, the difference in the blood supply to the right and left ears can be observed very clearly. A great many more blood vessels are seen in the left ear than in the right. If the sympathetic nerve leading to the left ear is stimulated by an electric current, the vessels of this ear begin to constrict within the next few seconds after the application of the current. If a sufficiently strong electric current is applied to the nerve, the ear loses its colour completely.

This experiment proves that the constriction of vessels is due to the influence of the *sympathetic nerves,* whose branches extend to the muscles in the walls of the vessels.

The dilation of blood vessels is controlled by the nervous system in exactly the same way.

The influence of the nervous system on the work of the heart and of the vessels. The work of the heart and the amount of blood that fills up the vessels may change in response to stimuli applied to the various sensory (afferent) nerves. Thus, the action of cold on the skin causes the blood vessels of the skin to constrict (pallor of the skin), while the action of heat causes them to dilate (reddening of the skin). A sudden dive into cold water may bring about "failure" of the heart; that is, the heart stops beating for a short time. Such "failure" of the heart and constriction of the blood vessels of the skin may occur in response to a sudden loud noise. Similar responsive reactions, brought about with the participation of the nervous system, are called reflexes, as we already know.

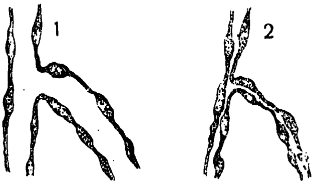

Fig. 56. Capillaries *(1)* in a dilated and *(2)* in a constricted state.

A great influence is exerted on the heart and the blood vessels by impulses coming from *the cortex of the cerebral hemispheres.* Examples of this are the intensified beating of the heart, or, on the contrary, sudden stoppage of the heart beats for a time, and also flushing or pallor of the face when a person is either agitated or frightened. The influence of the cortex of the cerebral hemispheres on the work of the cardio-vascular system varies, depending upon the mood, — whether a person is in a cheerful mood or in a depressed one, or whether he performs his work eagerly or without any desire.

The self-regulation of the cardio-vascular system. The stimuli which come from the vascular system itself play an important role in the regulation of heart activity. In the walls of the heart and of the blood vessels are imbedded *the endings of afferent nerve fibres.* In some of them a state of excitation is aroused when a blood vessel distends; in others, a state of excitation is aroused when certain chemical substances, for example, carbonic acid, act upon them. Impulses travelling along the afferent fibres reach the central nervous system, namely, *the medulla oblongata,* where the so-called *cardio-vascular centre* is located. Here response impulses arise, which, travelling along *the efferent nerves,* reach the heart and the blood vessels, and bring about reflex changes in their activity.

Many years ago a Russian scientist established the fact that when the pressure of the blood in the aorta becomes too great and its walls are greatly distended, a state of excitation is aroused in the endings of the afferent nerve in the walls of the aorta. The *excitation is transmitted to the central nervous system and further to the vagi, and then reaches the heart, which begins to contract less frequently and more feebly, as a result of which the blood pressure is reduced to normal.*

It sometimes happens that the flow of blood to the right half of the heart is greatly increased and the heart has no time to throw off this blood into the pulmonary artery. In such cases, the superior and inferior venae cavae and the right auricle begin to dilate, thus exciting the endings of the afferent nerves that are in the walls of the vessels and in the auricle. The excitation proceeds to the brain, which brings about intense excitation of the sympathetic nerves, and depression of the vagi. As a result, the heart begins to contract more frequently and more intensely, and is now fully able to throw off all the blood that flows into it.

I. P. Pavlov was the first to establish the importance of these reflexes. He proved that the blood-vascular system regulates itself to a definitely determined extent and, as a result of this, too abrupt changes in the work of the heart and of the vessels are next to impossible.

Chemical regulation. Various substances, which are discharged into the blood by the different organs, also exert an influence on the work of the heart and on the distribution of blood to the separate organs. This method of regulation is called chemical or *humoral*[1] regulation, that is, regulation accomplished by means of the blood.

Of the various substances that affect the cardio-vascular system, adrenaline and acetylcholine are of special importance. Under the control of the nervous system both are constantly being formed in the organism in greater or lesser quantities. The heart and the blood vessels react to *adrenaline* in the same way that they do to the stimulation of the sympathetic nerves; if adrenaline is introduced into the blood, the vessels constrict and the heart contractions increase in frequency and intensity. *Acetylcholine* produces a reverse reaction: it weakens the heart contractions, reduces their frequency, and dilates the blood vessels.

As a result of nerve and humoral regulation there is a careful and economical expenditure of power by the heart. The proper and constantly changing distribution of blood among the various organs serves as a protection to the heart against overwork, and thus the organism is able to get along with only four or five kilograms of blood.

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[1] From the Latin "humor" which means moisture.

Questions. 1. Why is it harmful to do physical exercises or to go bathing after a hearty meal?

Explain the proverb: "A full stomach is deaf to work and to study."

Problem. Count the beats of your own pulse in the morning, when still lying in bed. What is the amount of blood that flows through the left half of the heart in one minute, if the heart pours into the aorta 60 *cm.*^{3} of blood at each contraction? Make a similar calculation, counting the pulse beats immediately after fast running or hard physical work; in doing this, it is necessary to take into consideration that the amount of blood that passes into the aorta with each heart contraction is equal to 90 *cm.*^{3}

22. Exercising the heart

A weak and a strong heart. The heart performs a vast amount of work when we walk up a flight of stairs, run quickly or do any strenuous physical labour.

The work of the heart may be intensified in two ways: 1) by increasing the frequency of the contractions; 2) by increasing the amount of blood poured out with each contraction. When both of these occur simultaneously, the amount of blood which the heart is able to pump out each minute may be increased about five times and even more. However, circulation is usually quickened, for the most part, by increasing the frequency of the rhythm, or by increasing the amount of blood which passes into the aorta with each contraction of the heart.

In an athletically trained person, who does gymnastics and goes in for sport, and who is accustomed to physical work, the work of the heart is intensified mainly by increasing the amount of blood pumped out with each contraction. But it is only when the work performed by the heart is exceedingly strenuous that the frequency of the heart contractions is greatly increased.

In a person not athletically trained, leading a more or less sedentary life and unaccustomed to physical work, the heart is able to change the magnitude of the contractions only to a slight extent. The heart intensifies its work almost exclusively by increasing the frequency of its contractions. This greatly shortens the whole cycle of the work of the heart (the period of contractions and the pauses). Thus, with 160 to 180 contractions per minute, each cycle is completed in less than 0,4 of a second. At such a rate, the contraction of the ventricles takes place so quickly that they are not able to develop the contraction to its full power and to pump out all the blood they contain. Moreover, the pause, during which the heart rests and is filled up with blood, hardly occurs. As a result, the work of the heart muscle becomes weaker, and the amount of blood that comes from the veins to fill up the heart is diminished.

The reserve power of the heart. The reserve power of the heart is its capacity to increase its work, that is, to increase the amount of blood pumped out.

The reserve power of the heart of an athletically trained person is shown in fig. 57.

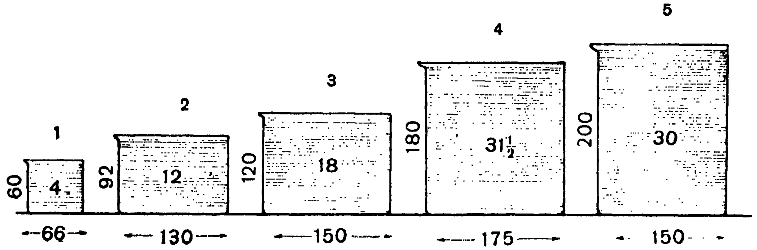


Fig. 57. Work of the heart of an athletically trained person:

1 — when in a lying position; *2* — walking quickly; *3* — running at a low rate of speed; *4* and *5* — running at an increased rate of speed. The width of the beakers indicates the amount of blood poured out by the heart into the aorta with each contraction (in cubic centimetres); the height indicates the number of contractions per minute; the number on each beaker indicates the amount of blood, in litres, that passes into the aorta in one minute.

The amount of blood pumped out by the heart in one minute increases in proportion as the demands made upon the heart keep on increasing. In an athletically trained person, this is at first achieved mainly by the magnitude of each contraction. It is only when the work is very strenuous that the number of contractions begins to show a decided increase — 160 to 180 per minute. If the load is still further increased, the heart simply cannot cope with it: the contractions become still more frequent, but their magnitude is diminished, and the total amount of blood pumped out is decreased from 31,5 to 30 *l.* per minute. The heart lags behind the needs of the organism, and the work is beyond the strength of the person to perform.

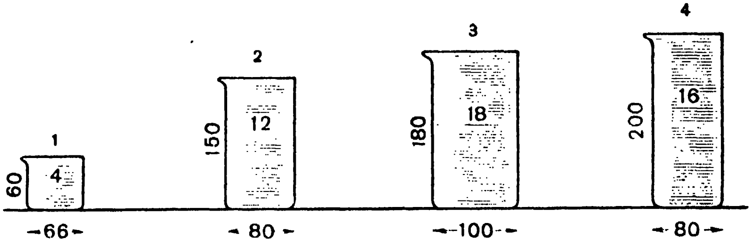


Fig. 58. Work of the heart of a person without any athletic training. The denotations are the same as those in figure 57.

The heart of a weak person, not athletically trained, possesses a very small reserve power. In figure 58 we see that the amount *of blood pumped out in a minute by such a heart could be increased only $4^1/_2$ times (from 4 to 18 l.) Furthermore, the pulse* beats rose to 180 per minute, while the magnitude of the contractions was only slightly increased (from 66 to 100 *cu. cm.*). When the demands made upon the heart were further increased, the work of the heart was certainly not intensified, but was even diminished.

Exercising the heart. Every person must try to strengthen his heart and to increase its reserve power, in order that it should be able to cope with the strenuous and prolonged work which life often calls upon it to perform.

In cases of pneumonia and other serious illnesses, the death of a patient most often depends on the activity of the heart; the heart appears to be too weak to meet the increased demands made upon the organism in connection with the illness.

In order that the heart should be strong and healthy, one must exercise the heart muscle. For this purpose, one must make greater demands upon the heart, and make them oftener; one must force it to perform strenuous work. In other words, one must lead an active life: in rest periods one must walk more, and go in for games in the open air and for sport. Morning setting up exercises are especially important for the strengthening of the heart and of the whole organism.

Working activity helps to strengthen the heart muscle. However, many kinds of work, especially sedentary work, do not exercise the heart. In such cases, it is especially important to exercise the heart muscle by means of gymnastics and sport.

In choosing a method for exercising the heart, a person's age and condition of health must be taken into consideration; it is therefore necessary to consult a doctor before beginning any such exercising of the heart.

Over-fatigue of the heart. If the heart is forced to perform strenuous work that is beyond its strength, it quickly becomes fatigued, its contractions become weaker, the amount of blood pumped into the aorta is decreased.

A great strain on the heart muscle does not help to strengthen the heart, but, on the contrary, reacts in a harmful way on the work of the heart and on the general state of the organism. If the heart is frequently over-strained, it becomes stretched, and the heart muscle becomes limp and flabby.

People with over-fatigued hearts are not able to do hard work; they go up a flight of stairs with difficulty, and what is especially important, they are likely to succumb to serious illnesses. The heart activity of such people may become greatly weakened, and even death may come as a result of the stoppage (paralysis) of the heart, or, as it is sometimes called, heart failure.

Conditions which bring about the weakening of heart activity. Weakening of heart activity may come as the result of too strenuous physical labour, over-indulgence in sport, prolonged mental work accompanied by sleepless nights.

Very often the regular work of the heart is destroyed by smoking.

The continued use of alcohol often brings about the fatty degeneration of the heart muscle, so that the muscle tissue is gradually replaced by fatty tissue. The accumulation of fat weakens the heart muscle, and the work of the heart may become insufficient.

REVIEW QUESTIONS

1. What is the internal medium of the organism called, and what is its significance?
2. Of what significance is the movement of the blood in a circuit?
3. What are the peculiarities in structure of the arteries, veins and capillaries?
4. What is the difference between arterial and venous blood?
5. In which arteries does venous blood flow? In which veins does arterial blood flow?
6. Describe the structure of the heart. Why does the blood inside the heart move in one direction?
7. What is meant by rhythm of the heart contractions?
8. Why does the blood pressure change in different parts of the blood-vascular system?
9. What is the pulse?
10. Why and how does the rate at which the blood moves change in different parts of the vascular stream?
11. Of what importance is the slow passage of blood in the capillaries?
12. How does muscle activity affect circulation?
13. How is the woik of the heart regulated?
14. What is the cause of any change in the filling up of the organs of our body with blood?
15. What is meant by the self-regulation of the cardio-vascular system?
16. How does the work of the heart change in an athletically trained person, and in one who has had no athletic training, with the varying activities of the organism?
17. What may cause over-fatigue of the heart?

23. The composition of the blood

Blood precipitation. Blood is not transparent, and its colour is red. It is a liquid containing a great number of very minute blood corpuscles, floating about in the liquid and visible only under the microscope (see coloured plate III). The blood corpuscles may be separated from the liquid part of the blood, if we add some substances to the blood to prevent it from coagulating and forming clots. After the unclotted blood has settled, or precipitated, two layers may be very clearly differentiated: the lower layer consists of blood corpuscles and is not transparent; it is of a dark red colour and is covered with an exceedingly thin whitish film; the upper layer is a very transparent, slightly yellowish liquid.

Plasma. The liquid part of the blood is called plasma. *More than 90% of the plasma is composed of water. About 1% of it* is composed of sodium chloride, sodium carbonate and some other inorganic salts. The rest is made up of proteins (about 7%), grape sugar (0,1 to 0,12%) and a small quantity of many other substances which are necessary for the cells of the body, or which constitute the products of their activity. The plasma also contains certain gases, particularly oxygen and carbon dioxide.

The white blood corpuscles. The thin, whitish film which covers the dark red sediment consists of white blood corpuscles, or *leucocytes*. These may be found in the blood of vertebrates and of invertebrates alike. Vertebrates have several kinds of white corpuscles, each kind possessing properties specific to itself.

A white corpuscle is a cell resembling an amoeba. Like the amoeba, the white corpuscle may change its form and move about. The white corpuscles can move along the walls of the blood vessels and even in a direction opposite to the blood current. Moreover, they force their way through the thin walls of the minutest vessels, get into the intercellular and tissue spaces, and wander about in the tissues of the body (Fig. 59), or issue onto the surface of the mucous membranes.

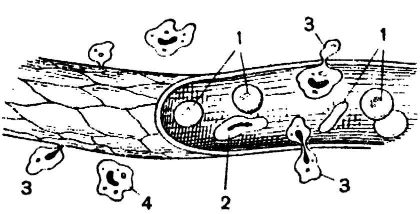


Fig. 59. White blood corpuscles issuing from the blood vessels and entering the intercellular spaces.

The blood vessel is partly cut open; inside are seen red *(1)* and white *(2)* corpuscles; *3* — white corpuscles in the act of pushing their way through the wall; *4* — white corpuscles wandering about outside the vessel.

Those white corpuscles that come out onto the surface of the mucous membranes usually die. They perish in vast numbers in the pus of inflammations (in an abscess, for instance), in inflammation of the respiratory tract. Pus consists almost wholly of dead white corpuscles.

The number of white corpuscles is not constant: it increases after meals, and with muscle work. In general, the number usually varies from 5000 to 10 000 per cubic millimetre.

The red blood corpuscles. Besides white corpuscles, the blood of vertebrates contains a great number of red blood corpuscles, or *erythrocytes*. The red corpuscles give the blood its red colour. The erythrocytes of a human being have the shape of double concave discs. They differ from the leucocytes in that they have neither the power of independent motion, nor the ability to change their form.

The erythrocytes of fish and amphibians have a large nucleus, which occupies a considerable part of the corpuscle. These nuclei are comparatively small in reptiles and birds. The red corpuscles of mammals and of the human being have no nuclei at all. However, the red corpuscles of the human embryo and of the embryo of mammals possess nuclei for a certain length of time. This proves that the erythrocytes gradually lost their nuclei in the process of the historical development of the animal world: at first the nuclei diminished in size, and then they disappeared altogether.

In one cubic millimetre of human blood there are 4,5 to 5 million red corpuscles. Therefore, there are 500 to 1000 red corpuscles for each white corpuscle.

Blood platelets. The erythrocytes, as we have said, are non-nucleated cells, but the blood platelets are not even cells, they are merely tiny particles of protoplasm. They are considerably more minute than either the white or the red corpuscles. There are from 300 000 to 500 000 of these blood platelets in one cubic millimetre of blood.

When the blood flows out of a vessel, the platelets stick to one another and form small clots.

The formation of blood corpuscles. The red corpuscles, like the white ones, die and disintegrate. New corpuscles are continually being produced in the organism to replace the dead ones. The organs in which the formation of blood corpuscles takes place are called *blood-producing organs*. The chief blood-producing organ is *the red marrow of bone*. Here the red as well as the white corpuscles are produced. Certain kinds of white corpuscles are produced in *the spleen* and in *the lymph nodes*.

Problem. Make a drawing of human blood as seen under the microscope.

24. Erythrocytes and their function

Hemoglobin. The red blood corpuscles, or erythrocytes, are oxygen carriers.

The chief component part of erythrocytes is an exceedingly complex substance — hemoglobin. Hemoglobin is a compound of protein and of a peculiar dye-stuff containing iron. Hemoglobin readily unites with oxygen, and just as readily gives it up. When the blood flowing through the lungs is saturated with oxygen, almost all the oxygen combines with the hemoglobin of the red corpuscles. But when the blood passes into the organs, where the oxygen has already been used up by the cells, the hemoglobin gives up its oxygen to the cells.

The size and shape of erythrocytes. Oxygen is absorbed through the surface of the red corpuscles. The greater the surface, the more quickly and the more completely does the hemoglobin of the red corpuscles become saturated with oxygen. The surface space depends on the size and shape of the corpuscles. The changes in the surface space may be demonstrated by breaking up a cobble-stone, for example, into small pieces. The surface space of the whole cobble-stone is much smaller than the surface space of *all the pieces into which the stone has been broken. The smaller* the pieces, the greater will be the total surface space.

Figure 60 shows the erythrocytes of various animals and of a human being. The red corpuscles of mammals are very much smaller than those of birds, fish and amphibians. The tiny erythrocytes of mammals and of the human being have a greater surface space per given volume than the large corpuscles of other animals. Moreover, each particle of hemoglobin in the small corpuscles is situated closer to the surface and can therefore unite with oxygen more readily.

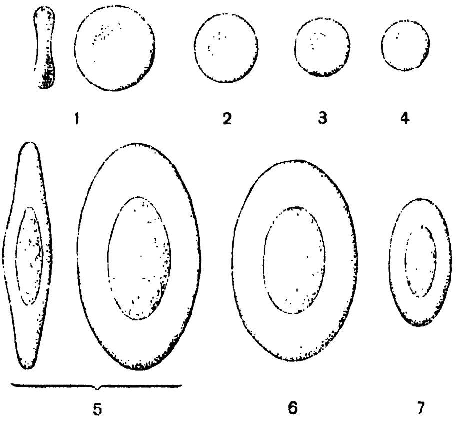


Fig. 60. Red blood corpuscles of a human being and of various animals.

In the upper row are corpuscles without any nuclei; in the lower row are corpuscles that have nuclei: *1* — elephant; *2* — man; *3* — horse; cow; *4* — goat; pig; *5* — fish (skate); *6* — frog; 7 — pigeon.

The shape of the human red corpuscles (double concave discs) increases their surface space still more in relation to their volume.

Thus, both the size and the shape of human red corpuscles provide for the most complete and rapid saturation of hemoglobin with oxygen.

The significance of the absence of a nucleus. The erythrocytes of man and of all mammals are short-lived, due to the fact that they contain no nuclei; therefore, billions of new corpuscles must be produced daily in the marrow of the bone. However, thanks to the absence of a nucleus, the red corpuscles are richer in hemoglobin, and therefore fill up still more completely with oxygen. This is an advantage of great significance to man, whose need for oxygen is very great.

Anaemia. Illness, poor nutrition, or loss of blood may give rise to a serious reduction in the number of the red blood corpuscles. Sometimes the number of corpuscles remains normal, but the hemoglobin content in each corpuscle is reduced. In either case, the ability of the blood to absorb oxygen is diminished. As a result, the organism does not receive enough oxygen, and the oxidation processes are retarded. This causes general weakness and sluggishness, a bad appetite and rapid exhaustion of the organism. Such a condition of the organism is known as anaemia.

Questions. Why do people who live high up in the mountains have an increased amount of red blood corpuscles (sometimes as much as 8 million in one cubic millimetre of blood)? With what special constituents of the air is this connected? Of what importance is this to the organism?

25. Coagulation, or clotting, of the blood

Observation of the coagulation of blood. Let us pour into a test-tube some blood freshly drawn from a blood vessel. We see that the blood begins to thicken rapidly. In a few minutes all the blood coagulates, turns into a jelly-like clot, and does not pour out of the test-tube. If we continue watching the clot for several hours, we will see that it gradually shrinks up and stands away from the walls of the test-tube, and that a yellowish liquid collects around it (Fig. 61).

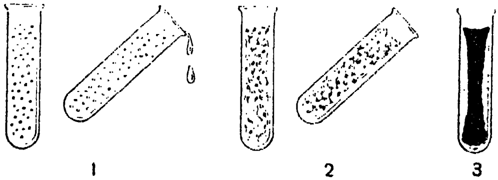


Fig. 61. Formation of a blood clot:

1 — test-tube with freshly drawn blood; *2* — coagulated blood; *3* — the clot in a shrunken state.

If the process of blood coagulation is observed under the microscope, it may be noticed that very fine filaments appear, one after another, in the plasma. These interlace, gradually forming a thick network, in the meshes of which the blood corpuscles are entrapped (Fig. 62).

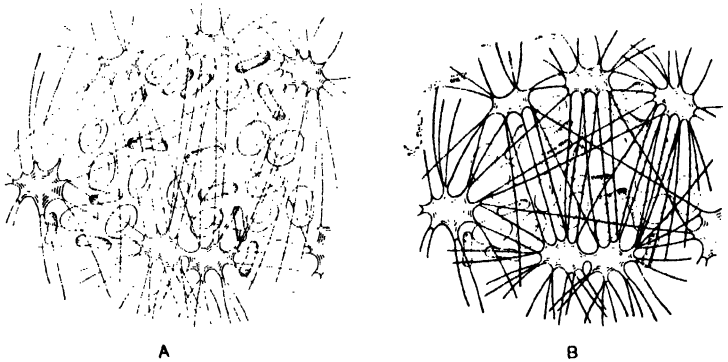


Fig. 62. Coagulation of the blood:

A — initial stage of coagulation: little lumps of fused blood platelets, from which extend threads of fibrin, are seen; among the threads there are blood corpuscles; *B* — the clot in a shrunken state; the threads of fibrin in a thickened and shortened state.

Fibrin. Blood is capable of coagulating because, besides other proteins, the plasma contains a small quantity of the protein, *fibrinogen*; fibrinogen is easily converted into the solid state and is precipitated out of solution in the form of very fine filaments which form the clot. In its insoluble state this protein is called *fibrin.*

Fibrin may be easily obtained by beating up, with thin little sticks or twigs, some fresh blood drawn from a blood vessel: a mass of the thin fibrous filaments of fibrin will collect on the twigs or sticks.

The serum of the blood. The blood which remains after the fibrin has been separated from it is not capable of coagulating any more. If this blood is left in the test-tube, the blood corpuscles gradually settle to the bottom; above them remains a transparent, yellowish liquid, which is called serum, and which differs from plasma only in that the fibrin has been separated from it. Serum may also be obtained at the ordinary clotting of blood: serum is the liquid which issues from the clot when the clot shrinks.

Ferments, or enzymes. In order to understand the complex process of blood coagulation, we must make a study of a remarkable property of the organism.

Various chemical transformations, sometimes very complex ones, go on in all the organs and tissues of the body. Most of these reactions, if we try to reproduce them in the laboratory, require conditions that never occur in the organism. As we know, the speed of chemical processes depends upon the temperature: the higher the temperature, the more rapid and energetic the chemical reaction will be. Many processes, among them the process of the oxidation of carbo-hydrates, which goes on in the organism on such a large scale, may be brought about outside the organism only at a very high temperature. But these very same processes take place with great speed, at body temperature, inside the organism.

Some chemical reactions occur with greater force and speed when certain substances are present. These substances are accelerators, or *catalytic agents.* Similar accelerators of reactions may be found in any organism. They are called *ferments*, or *enzymes.*

Ferments are produced by the cells of the living organism. Their role is extraordinarily great: ferments of different kinds are active and absolutely necessary participators in the vast majority of chemical processes that go on in the organism.

The properties of ferments, or enzymes. One of the most remarkable properties of ferments is that their mere presence is enough to bring about a reaction. They are, so to say, the mediators in chemical processes, while their quantity hardly changes during the reaction. Thus, a very small quantity of ferment is enough to convert dozens of kilograms of animal starch into sugar.

Ferments act best at body temperature. If the temperature is lowered, their action weakens. Boiling destroys ferments.

Ferments possess the important property of being specific. This specific quality of ferments expresses itself in the fact that each ferment can bring about only certain definite chemical reactions.

The role of ferments in blood coagulation. There are several different kinds of ferments in the blood. One of them is *thrombin,* which participates in the coagulation of blood.

Thrombin usually occurs in the blood in an inactive state. When acted upon by a special substance — "*an activator*" — the thrombin is converted into an active state, and then the blood begins to coagulate. Under normal conditions, the blood does not coagulate, because there is no "activator" in it. The "activator" is contained in the blood platelets. When the blood platelets disintegrate (and they always disintegrate as soon as the blood flows out of the vessels), an "activator" appears in the blood; the thrombin is converted into an active state, and turns the soluble fibrinogen into insoluble fibrin.

The participation of lime salts, which are always present in the blood, is an absolutely necessary condition for the coagulation of blood. If certain chemical substances (for example, oxalate of sodium) are added to the blood, the lime salts are precipitated, and the blood loses its ability to coagulate. When we want to prevent the coagulation of fresh blood drawn from a vessel, we add a small amount of oxalate of sodium to it.

Thrombosis of the blood vessels. The blood inside the blood vessels does not coagulate. But, sometimes, in cases of rheumatism and some other diseases, the inner membrane of the heart or of a blood vessel is affected. The blood begins to coagulate at the place which has become affected, and little clots of blood, or *thrombi,* are formed. If a tiny particle of a thrombus is torn away, it may be carried by the blood stream into some organ, and there bring about thrombosis of a blood vessel. Thrombosis of the vessels of the brain or of some other organs may be the cause of serious illnesses, and sometimes even of death.

The importance of blood coagulation. The importance of blood coagulation is clear: the clot stops up the opening of an injured vessel, and further bleeding is checked. If clots did not form when blood flowed out of a vessel, the slightest wound would cause bleeding without any stoppage, and death would inevitably result.

The greater or lesser losses of blood that occur during a surgical operation depend, to a large extent, on the speed with which the blood of the patient coagulates. With some patients, coagulation takes place so slowly that the slightest cut is followed by prolonged bleeding. Before beginning an operation, the surgeon should examine the patient's blood in order to determine the speed with which it coagulates.

In the Soviet Union, where special means are used to intensify the coagulating ability of the blood, surgeons proceed to operate with assurance on all patients.

Bleeding, or hemorrhages. There is often considerable bleeding in cases of wounds or injuries. Bleeding may be arterial, venous and capillary, depending upon which vessels have been injured.

The most dangerous of all is *an arterial hemorrhage*. The blood, subjected to great pressure, spurts from the injured artery with force, sometimes in the form of a pulsating fountain.

In cases of *venous bleeding*, the blood flows out in an even stream, without any noticeable pressure.

In cases of severe venous hemorrhages, and especially of severe arterial hemorrhages, there is not enough time for clots to form on the edges of the wound; and if clots do form, they are immediately torn off and carried away by the outflowing blood.

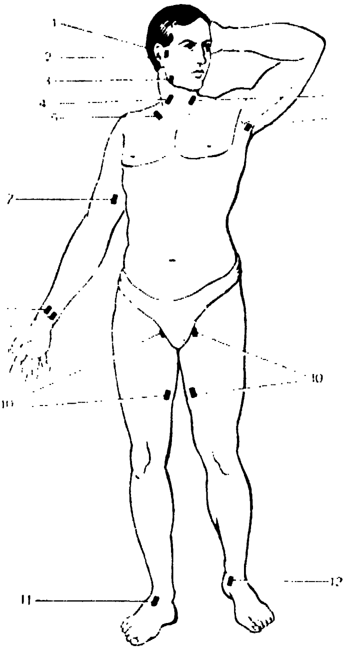


Fig. 63. Points where the arteries are compressed in cases of bleeding:

1 — occipital artery; *2* — temporal artery; *3* — maxillary artery; *4* — carotid arteries; *5* — subclavian artery; *6* — axillary artery; *7* — brachial artery; *8* — radial artery; *9* — ulnar artery; *10* — femoral artery; *11* — anterior tibial artery; *12* — posterior tibial artery.

When the wound is on the surface of the skin, it is usually only the capillaries and the smallest arteries and veins that are injured. In such a case, the whole surface of the wound bleeds and becomes covered with tiny drops of blood. Such bleeding is called *capillary bleeding.*

How to stop bleeding, or hemorrhages. In order to stop capillary bleeding, as well as slight venous and arterial bleeding, it is enough to bandage the injured part, after having first put some gauze, cotton wool or strips of gauze bandage on the bleeding wound.

In case of a severe arterial hemorrhage, it is necessary immediately to compress well with the finger the artery which is bringing blood to the injured part of the body. The places where the most important arteries of the body should be compressed in cases of bleeding are shown in figure 63. By feeling for these places on one's own body, one may learn to locate them quickly and easily.

In order to compress the artery for a prolonged period of time in cases of injury to the arms or legs, a ligature is used in the region of the humerus or femur. A rubber tube or a leather belt, a gauze bandage or handkerchiefs etc., may be used as ligatures. To compress the artery better, a tightly rolled gauze bandage or a ball of some clean cloth is inserted under the ligature. A ligature inside the bandage should not be used for more than one or two hours. If it remains there for a longer time, mortification of the tissues may set in.

Blood clotting is considerably accelerated if the bleeding is first partially stopped by compressing the artery and then by binding it tightly with a bandage.

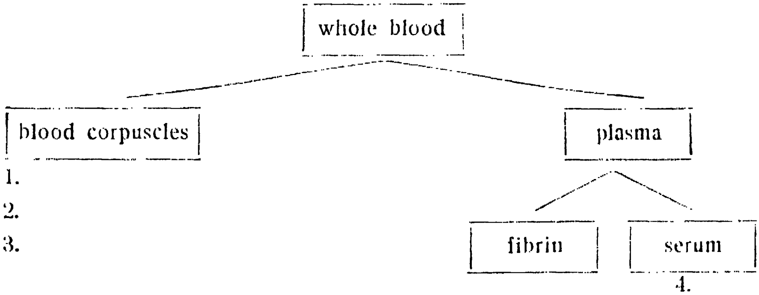
In case of a severe hemorrhage, a physician should be sent for without delay, while the above mentioned first aid measures are being applied.

In order to lessen the drainage of blood from the brain and to facilitate the work of the heart, the head of the injured person should be placed a little lower than the trunk of the body, while the arms and legs should be raised; hot water bags, or bottles with hot water, should be applied, and hot drinks given often to keep the patient warm.

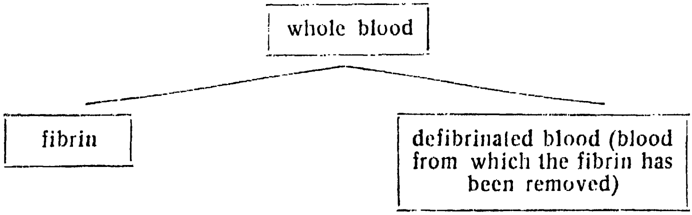
The application of thrombin. Soviet scientists have succeeded in working out a method of producing thrombin out of the plasma of the blood; gauze soaked in a solution of such thrombin quickly checks bleeding. This method was successfully used during the Great Patriotic War, especially in cases of wounds in the brain and in the internal organs.

Question. When children play out in the cold, they sometimes get scratches or abrasions which bleed for a long time. How can you explain such prolonged bleeding?

Problems. 1. Copy the diagram given below of the composition of the blood. Instead of the figures 1, 2, 3, write the names of the blood corpuscles, and in parentheses show their importance. Instead of the figure 4, enumerate all that enters into the composition of serum.



2. A part of a somewhat different diagram of the composition of the blood is given below. Copy this diagram, finish it, giving the necessary explanations. Give a written account of the differences between the first and the second diagrams.


whole blood
fibrin
defibrinated blood (blood from which the fibrin has been removed)

3. Using figure 63, find on your own body the points where the most important arteries of the body are compressed in cases of bleeding.

26. The defensive properties of the blood

Contagious diseases. *There are vast numbers of microbes in* the soil, in the air, in water — everywhere. We are constantly swallowing them with our food, with water; we breathe them in with the air. Most of the microbes are not harmful to us, but some microbes that get into the organism may prove to be carriers of disease. Illnesses brought about by microbes are called *contagious*, or *infectious*, *diseases.*

A person is always in contact with the germs of tuberculosis, diphtheria and many other diseases. However, it must not be thought that illness sets in each time microbes find their way into the organism. A disease is contracted when the microbes that get into the organism find favourable conditions for their reproduction and overcome the resistance of the organism.

There is a continual struggle going on between the microbes and the organism, upon the outcome of which depends the health, and sometimes even the life of a person. When the microbes of some contagious disease find their way into the organism and quickly die there, without infecting the organism with that disease, we speak about the immunity of a person to the given disease.

There are a great number of defensive substances in our body that prevent the formation of diseases. Thus, for example, many microbes that enter the stomach die there as a result of the action upon them of hydrochloric acid, which is one of the constituents of gastric juice; mucus, secreted by the mucous membrane, also has a destructive effect upon many microbes and, in any case, prevents their rapid reproduction.

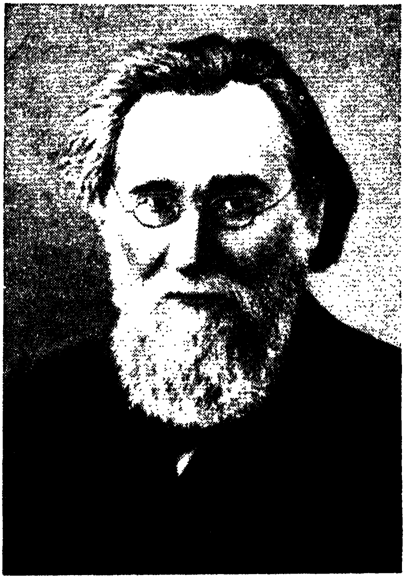
Inflammation. Each organ responds with a defensive reaction to mechanical injury, such as a bruise, a wound or a burn, as well as to the presence, in the tissue, of microbes or any other irritating substances as, for example, concentrated acids.

The blood vessels of the affected area dilate, the white blood corpuscles issue from the vessels in great numbers and collect round the foreign bodies and round the whole infected section. Such a reaction of the organism is called inflammation. The inflamed part of the body, due to the rush of blood to that spot, usually becomes red and warmer than normal. The flow of fluid from the blood in the interstices and spaces of the tissues is increased and causes the inflamed part to swell.

The inflammation of an organ, for example, of the lungs, the bronchi (bronchitis), the kidneys, etc., is often accompanied by a general rise in temperature. In other cases, inflammation is of a local character. Inflammatory skin reactions of a local character are those that occur frequently when the skin is injured or when foreign bodies (such as splinters) get into it. The nervous system, by influencing the processes of metabolism, determines the course which an inflammatory reaction will take.

The inflammatory reaction facilitates the work of the organism in its struggle against any injury, whether it is a burn, a bruise, or an attack by microbes that have penetrated into the organism. But how, after all, is this struggle conducted? How does the organism defend itself against contagious diseases? Upon what does the insusceptibility to disease fundamentally depend? The answers to these questions were given by the outstanding Russian scientist, Metchnikov.

I. I. Metchnikov, the founder of the theory of immunity. I. I. Metchinkov, whose name is known throughout the whole world, was born in 1845. His interest in the natural sciences began when he was only eight years old; when he was a first-year student at the university, his first serious scientific work was printed. Metchnikov studied invertebrate animals for a period of twenty years, and made many very remarkable scientific investigations. But he was always eager to do more and better work. From his very youth, he dreamed of doing work that would be of service to mankind, that would bring more happiness to humanity.



I. I. Metchnikov

Metchnikov was fortunate enough to realize his dream. In 1882 he made a discovery that immortalized his name. He proved that the white blood corpuscles play an important defensive role: they attack and destroy microbes.

I. I. Metchnikov devoted the rest of his life to the study of the struggle of the organism against contagious diseases. He can truly be called the founder of the theory of *immunity*, that is, of insusceptibility to contagious diseases.

Another branch of his work dealt with the problem of the fight against premature old age.

Because of the obstacles that were continually put in his way in tzarist Russia, Metchnikov was forced to leave his native country and to settle in France.

"It might be thought," wrote Metchnikov later, "that in Russia the time has not yet come when science might prove to be useful. I do not agree with this. On the contrary, I think that, in Russia, scientific work is a necessity, and I hope with all my heart that the future will bring more favourable conditions for it."

Metchnikov came to Russia very rarely during the 28 years of his life in France, but during that time he kept up an uninterrupted connection with Russian scientists. Hundreds of Russian physicians and scientists worked under his leadership in the famous Pasteur Institute in Paris.

I. I. Metchnikov always dreamed of a time when Russia would be free, and when conditions would at last be created under which science could flourish there. These conditions were created by the Great October Socialist Revolution, which I. I. Metchnikov did not live to see, — he died in 1916.

The role of the white blood corpuscles. The basis of Metchnikov's theory of immunity is his work of investigation concerning the role of the white blood corpuscles. With the help of their movable projections, leucocytes can seize and engulf solid particles, and then dissolve and digest them in their bodies.

Great numbers of white corpuscles may be found wherever there are cells in an injured state or in a state of disintegration, or wherever any foreign bodies, including microbes, appear. The leucocytes seize upon and engulf what is left of the disintegrating cells of the body, and also the microbes that have found their way into the organism (Fig. 64). This is exactly why white corpuscles often collect in vast numbers in an inflamed part of the body.

Besides possessing the ability to seize upon and absorb microbes, white corpuscles are also able to produce antidotes to various noxious and poisonous substances that may enter the organism.

Phagocytosis. Cells that have the ability to engulf various bodies, including microbes, may be found not only in the blood, but also in the various organs of the body, especially in the spleen and in the liver.

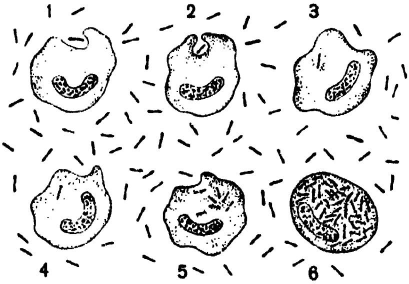


Fig. 64. Phagocytosis:
1 — 5 — successive stages of microbe engulfment; 6 — pus corpuscle.

This can be proved by introducing a liquid, in which are suspended small grains of India ink or of other dyes, into the blood of an animal; the grains disappear from the blood and soon appear again inside certain definite types of cells.

Metchnikov gave the name of *phagocytes*, that is, devouring cells, to the leucocytes, as well as to other cells, possessing the ability to engulf extraneous bodies. Phagocytes seize upon and digest not only microbes, but also various injured or disintegrating cells of the body. The phagocytes seize upon disintegrating erythrocytes in the liver and the spleen; they devour the cells in the hair that contain pigment (dye-stuff), as a result of which the hair turns gray. In the metamorphosis of the tadpole into a frog, the phagocytes take part in destroying the cells of its disappearing tail. Ths seizure and engulfment, or digestion, of various bodies is called phagocytosis.

Metchnikov's theory of phagocytosis laid the foundation for the contemporary notions concerning the struggle of the organism against contagious diseases. It may be said to be definitely determined that the insusceptibility of the organism to one contagious disease or another is connected with the ability of the phagocytes to destroy quickly and energetically the microbes that have invaded the organism. If phagocytosis proceeds slowly and sluggishly, the microbes in the organism multiply easily and, as a result, the disease is contracted.

The ability of the phagocytes to seize upon and digest microbes quickly depends, to a great extent, upon the properties of the blood and of other fluids in the body. It was ascertained long ago that the serum of the blood, which does not contain any blood corpuscles at all, can weaken the microbes, retard their reproduction, and even kill them. Similar substances that weaken the microbes were found in saliva, in mucus, and even in tears. The action of all these substances on microbes facilitates and intensifies phagocytosis.

Anti-bodies. If the germs, or microbes, of any contagious disease get into the organism, special protective substances — anti-bodies, appear in the blood. Each anti-body can destroy only one definite species of microbe. Thus, in the serum of a person who has suffered from typhoid, there are anti-bodies which act on the germs of typhoid, but which have no effect whatever on the germs of diphtheria. And, vice versa, the serum of a person who has been ill with diphtheria contains anti-bodies which destroy the germs of diphtheria, but which are harmless to the germs of typhoid.

Anti-bodies may possess various properties. In some instances, they cause the microbes that have invaded the organism to stick together in little lumps; in other instances, they dissolve the microbes or neutralize the poisons produced by them.

In killing or weakening the microbes and neutralizing their poisons, the anti-bodies create the conditions for the intensification of phagocytosis, and thus strengthen the organism, facilitating its struggle against contagious diseases. The susceptibility of a person to one disease or another depends, to a great extent, on the production of anti-bodies.

The formation of anti-bodies, just like any other process that goes on in the organism, is controlled by the nervous system, and especially by the higher division of the nervous system — the cortex of the cerebral hemispheres. This explains the well-known fact that the ability of the organism to fight disease depends upon the general state of the organism and upon the conditions in which the organism finds itself.

27. Immunity

Not all people are equally susceptible to contagious diseases of various kinds. Some people do not contract a disease, in spite of the fact that they may be in contact with sick people, or taking care of them. Such insusceptibility to a contagious disease is called immunity.

Natural immunity. Sometimes a person is insusceptible to some disease from birth. Usually, immunity to a certain disease is acquired after a person has had the contagious disease. Once a person has had typhus or small-pox, he is not likely to contract it a second time. His organism develops immunity to the given disease.

There are other contagious diseases to which a person who has had them may become immune for a very short time only, and sometimes not at all: for example, the grippe. *Inborn* immunity, as well as immunity that is *acquired* after an illness, is called natural immunity.

Artificial immunity. A person may be made immune to certain diseases by artificial means — with the help of corresponding *inoculations* or by *the injection of serums.*

The first attempts to bring about insusceptibility to contagious diseases originated in ancient times. More than a thousand years ago, attempts were made, in Georgia, to prevent the spread of small-pox by piercing the skin of healthy people with needles that had been immersed in the pus of small-pox. In Africa, inoculation has been used from time immemorial to protect a person from the fatal results of the bites of poisonous snakes.

At the end of the 18th century, Jenner, an English village doctor, discovered, as the result of the remarkable observations of many years, a correct and safe method of producing immunity artificially. Jenner proved that if a person was inoculated with cow-pox, he became only slightly ill with it and would later be insusceptible to small-pox — a very noxious and often fatal disease, peculiar to man.

In the years immediately following the publication of Jenner's work, inoculation with cow-pox, or vaccination, began to be widely used in all countries of the world, including Russia.

In spite of the evident success of vaccination, reactionaries raised a storm of protest against Jenner. "Scientists" appeared, who pointed out that if people were inoculated with cow-pox, they would be turned into animals. The pope at Rome proclaimed that all those who allowed themselves to be vaccinated were atheists. Members of the English Parliament delivered speeches in which they denounced inoculation with cow-pox (vaccination) as an infamous and criminal matter. Even now, vaccination is not, in reality, compulsory in England.

At the present time, there are protective inoculations against many diseases — small-pox, typhoid, typhus, diphtheria, dysentery, and other diseases. In all these cases, microbes that are either weakened or dead are injected into the organism of a person.

Before a person is inoculated with protective vaccine for small-pox, a calf is first injected with the disease. The calf gets the disease in a mild form; at the same time, the small-pox microbes in its organism become weakened. The liquid from the small-pox vesicles of the animal are transferred to the affected part of the skin of a person. The weakened microbes are not able to bring about a severe form of the disease in the person. Two or three vesicles appear on the part of the skin where the inoculation has been made; sometimes there is a slight feeling of discomfort, and the temperature rises, but then all passes away. As a result of vaccination, a person is safe from small-pox microbes, even if they are not in a weakened state. This may be explained by the fact that the organism has acquired the ability to produce quickly the anti-bodies which destroy the given microbes.

Serum used in medicine. To help a person in his fight against the microbes which have found their way into his organism, so-called medicinal serum may be injected into his organism.

It is known that the microbes of diphtheria usually settle on the tonsils of the throat. However, although they remain in that place, they poison the whole organism by secreting a powerful poison, or *toxin*, which brings about a severe form of the disease. The organism responds to the appearance of the toxin by beginning the production of a corresponding anti-body, which renders the diphtheria toxin harmless. This anti-body is found in the blood and is called *anti-toxin*, that is, anti-poison. If the anti-toxin is produced quickly and energetically enough, the organism has time to neutralize and even destroy the harmful action of the diphtheria poison. In many cases, however, the disease develops so quickly that the organism cannot manage to produce a large enough quantity of anti-toxin, and the patient dies. If medicinal serum, which already contains prepared anti-toxin, is injected in time through the lymph and the blood, it will spread throughout the whole organism and neutralize the diphtheria poison.

To-day medicinal serum is prepared not only for fighting against diphtheria, but also against a number of other diseases. To get medicinal serum with anti-bodies ready for use, an animal is immunized (for example, a horse or a rabbit); in other words, artificial immunity is brought about in the animal by injecting it with microbes, or with a toxin produced by the microbes, at first in small doses, and then in larger and larger doses. In this way, the corresponding anti-bodies are produced in the animal's blood. If the blood serum taken from such an animal is injected into the organism of a patient, then the patient receives, together with the serum, anti-bodies that are all ready for use.

Passive and active immunity. If the serum from an immunized animal is injected into the organism of a healthy person, im-

munity is developed, in the preparation of which the human organism takes no part: he gets anti-bodies ready for use together with the animal serum. Immunity produced without the participation of the organism is called passive immunity. As a rule, passive immunity lasts only for a short time, seldom for more than a month, but then, it is produced immediately after the serum is injected.

Artificial immunity, brought about by protective inoculations, is produced by the organism itself, and is therefore called active immunity. As a result of active immunity, the organism acquires the ability to produce its own anti-bodies. Active immunity lasts much longer — often several years and sometimes a whole lifetime. Active immunity takes some time to produce: after an inoculation, a week or two, and sometimes even more, must pass before the organism produces immunity.

The influence of the state of the organism on immunity. Sometimes a person may become infected and contract a disease in spite of protective inoculation. In such cases, the disease proceeds in a mild form, and is often limited only to some slight indisposition. Consequently, insusceptibility to disease is not always complete. It depends upon the extent to which the organism can resist the deadly action of microbes, and upon the extent of its ability to produce anti-bodies that will destroy microbes.

Susceptibility to disease may vary — it may increase or decrease, depending upon the state of the organism, and upon the conditions in which the organism finds itself.

Exposure to extreme cold diminishes the vital activity of the organism and, thus, by weakening its power, at the same time lowers its resistance to contagious diseases. The influence of cold on susceptibility to disease has been clearly demonstrated by a series of experiments on animals. The famous French scientist, Pasteur, infected some hens with so-called chicken cholera. Then the legs of some of the hens were immersed in cold water. As a result, the percentage of hens that contracted the disease was higher among those hens that had been subjected to the cold.

The state of the human organism and, consequently, its susceptibility to disease, is determined by the nervous system to a great extent. All the conditions in which a person lives and works, including his social conditions, act upon the organism through the nervous system, namely, through the cortex of the cerebral hemispheres. That is why fatigue, low spirits, depressed and moody thoughts, may increase the susceptibility to disease.

The successful struggle against contagious diseases in the U. S. S. R. In 1919, after the Great October Socialist Revolution, V. I. Lenin signed a decree making vaccination compulsory. Since that time, small-pox, from which so many people, in tzarist Russia, died and from which still more people became blind and disfigured every year, has disappeared in the Soviet Union.

There are no more plagues and cholera in our country. In comparison with pre-revolutionary times, the death-rate from tuberculosis has been greatly reduced.

In our country inoculations against diphtheria and scarlet fever are made in all the schools and kindergartens. Inoculations against typhoid, dysentery and other diseases are widely used. As a result, a fewer number of people of the U. S. S. R. contract typhus, dysentery, scarlet fever, diphtheria; while those that do contract any of these diseases, have them in a milder form. Medicinal serum, which facilitates the struggle of the organism against disease and hastens its recovery, is very widely used by us in treating contagious diseases. The role of medicinal serum is especially great in the fight with diphtheria. Very many children died of this disease in tzarist Russia. In Soviet times, death from diphtheria is very rare.

The general state of the organism is greatly influenced by the social environment, the social system under which a person lives and works. The exploitation of labour in capitalist countries not only lowers the living standard of the workers, wastes their energies and brings about exhaustion, but it also causes depression of the psychic state. All this, taken together, increases the susceptibility to diseases. And there is nothing strange in the fact that in bourgeois countries statistics show that disease-rates and death-rates are higher among the proletariat than among the ruling classes; while some diseases are found almost exclusively among the workers.

In the U. S. S. R. the exploiting class was destroyed, and thus, together with this class, disappeared even the possibility to exploit labour. Those social conditions which help to preserve the health and to reduce the susceptibility to disease are improving from year to year. As a result, the number of disease cases and the death-rates in our country have been greatly reduced in comparison with the pre-revolutionary period.

Question. If there is a case of contagious disease in a family (for example, diphtheria), in what way may immunity be produced in the organism of the person who is in contact with the patient? Explain why a different method is not suitable in the given case.

28. Blood transfusion

Reasons for the death of patients in blood transfusion. In certain diseases and in cases of severe hemorrhages, it is often necessary to transfuse into the blood of a patient a quantity of blood taken from a healthy person.

Formerly, repeated attempts had been made to transfuse the blood of an animal to a person. Such attempts usually proved fatal. However, even human blood is not always suitable for transfusion, though it may be drawn from a perfectly healthy person.

Careful study has shown that the death of patients after blood transfusion is due to the fact that the red blood corpuscles glue together.

This gluing together of the red corpuscles may be observed under the microscope, if we mix a drop of blood from a sheep with human serum: through the microscope we see, not separate red corpuscles, but little lumps consisting of a great number of corpuscles glued together. The same phenomenon may sometimes occur when the liquid part of the blood of one person is mixed with the erythrocytes taken from the blood of another person. If this happens during the transfusion of blood, the little lumps that are formed bring about thrombosis of the blood vessels and prevent the normal circulation of the blood, — a condition which may prove fatal.

In order that the red corpuscles should glue together, two conditions are necessary: firstly, the plasma must contain a special anti-body that will cause the red corpuscles to glue together; secondly, the erythrocytes must contain a substance that can be acted upon by that anti-body. Two different kinds of anti-bodies may be present in the plasma of human blood, and there may be two substances in the red corpuscles upon which these anti-bodies act.

Blood grouping. Blood never contains, at the same time, both the anti-body and the substance upon which this anti-body acts. If it did, the plasma would become glued to its own red corpuscles, and the circulation of the blood would become impossible.

All people may be divided into four groups, depending upon the presence in their blood of anti-bodies and of the substances on which these anti-bodies act.

The substances found in the erythrocytes are designated by the Latin letters A and B. The corresponding anti-bodies are designated by the Greek letters — α (alpha) and β (beta).

People with plasma containing both anti-bodies α and β belong to *the first group*; it is clear that there can be neither substance A nor substance B in the red corpuscles of such people. The blood of people of *the second group* contains only one anti-body — β; accordingly, substance A may be found in their red corpuscles, but never substance B. The plasma of *the third group* contains, on the contrary, anti-body α, while the red corpuscles contain substance B. The two substances — A and B — are contained in the red corpuscles of people of *the fourth group*; in the plasma of people of this group there is neither anti-body α nor anti-body β, and cannot be.

In blood transfusion, it is very important that the erythrocytes introduced into the blood should not glue together in the blood of the patient; the introduction of anti-bodies that act on the red corpuscles of the patient constitutes no danger. Therefore, blood of the first group, the erythrocytes of which contain neither substance A nor substance B, may be transfused to any person. But a patient with blood of the first group, which has both anti-bodies (α and β), can receive no other blood than that from a person of that same group.

Table 1 shows to what group the blood of a donor[1] must belong in order that it may be used for transfusion to a patient. Thus, for example, if the blood of a donor belongs to *the first*

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[1] A donor is a person who gives his blood to a patient.

group, it may be transfused to all patients; the blood of people of *the fourth group* may be transfused only to patients whose blood belongs to the same group.

Table 1

A donor's blood	A patient's blood			
	of the 1st group (α; β)	of the 2d group (A; β)	of the 3d group (B; α)	of the 4th group (A; B)
of the 1st group (α; β)	possible	possible	possible	possible
of the 2d group (A; β)	impossible	possible	impossible	possible
of the 3d group (B; α)	impossible	impossible	possible	possible
of the 4th group (A; B)	impossible	impossible	impossible	possible

The importance of blood transfusion. Blood transfusion has become absolutely safe and is used on a wide scale, due to the preliminary examination of the blood of the donor, as well as that of the patient. In many diseases, the life of a patient can be saved by this method. Transfusion acquires special significance in cases of great losses of blood, as, for example, from wounds.

No country makes use of blood transfusion to such an extent as our country. Our scientists have worked out new methods of conserving the blood, and also a method of utilizing the blood of a dead person.

During the Great Patriotic War a special "Blood Transfusion Service" was organized in the Soviet Union; the work of this organization saved the lives of many thousands of wounded fighters of the Soviet Army. Stations for the collection and conservation of blood to be sent to the front were organized in large towns of the Union. Five and a half million Soviet patriots gave their blood to save the lives of the valiant defenders of our country.

REVIEW QUESTIONS

1. What are the roles of the red and the white blood corpuscles?
2. What are ferments (enzymes) and what are their role in the organism?
3. Explain the process of blood coagulation, and state its significance.
4. What first aid must be rendered in the case of cuts and wounds?
5. Arteries are usually situated deeper in the body than veins; of what biological significance is this fact?
6. What are the protective properties of the blood? Why may inflammation be called a protective reaction of the organism?
7. What is phagocytosis?
8. What is immunity? What kinds of immunity do you know?
9. What helps to reduce the susceptibility of a person to disease?
10. Of what importance is blood transfusion? What rules must be observed in blood transfusion?

IV. THE ORGANS OF RESPIRATION

29. The significance of the respiratory organs

The importance of oxygen. Every living creature needs oxygen for the processes of oxidation that go on in its organism. During the process of oxidation, as well as during other chemical processes that bring about the splitting up and disintegration of the cellular substance, potential *energy* is released. Moreover, *the neutralization* of many poisonous waste products, which are produced in the process of cellular and tissue activity, takes place by means of oxidation.

One of the chief products formed as a result of the oxidation processes is carbon dioxide, or carbonic acid.

The interchange of gases between the organism and its environment. The organism is in constant need of taking in oxygen from the surrounding medium and of giving up the excess of carbon dioxide to the exterior. The interchange of gases between the organism and the external environment is called respiration.

Some marine invertebrates easily absorb, through the walls of their bodies, the oxygen dissolved in the water. They eliminate the carbonic acid produced in their bodies in the same way. However, many invertebrates have special respiratory organs, by means of which the gaseous interchange between the organism and its external environment is greatly intensified and facilitated.

The respiratory organs of vertebrates. All vertebrates have respiratory organs — even such animals as the frog, for example, in which the interchange of gases may be carried on through the skin. In the process of development of the animal world, these organs, like all the other organs, kept on changing and became more and more complex.

The respiratory organs of the lower vertebrates that live in the water are *the gills*. With the gradual transition of life in the water to life on land, air bags, or *lungs*, began to develop. Dipnoi fish and some amphibians have both gills and lung bags, which serve as additional respiratory organs.

The lung bags of the lower forms of amphibians (for example, the proteus), have smooth walls, as a result of which the contacting surface between the blood vessels and the air contained in the lungs is very small. The little folds that develop in the lung bag of the salamander increase the absorbing surface to some extent.

However, the lungs of amphibians do not provide for a sufficient interchange of gases. The chief organs of respiration in some of them are, as they were before, the gills. In frogs, in spite of the considerably greater development of the absorbing surface of its lungs, the interchange of gases goes on chiefly through its thin, mucus-covered skin, through which oxygen and carbon dioxide pass easily. A frog remains alive after its lungs have been removed, but it dies if respiration through the skin is artificially stopped, even though the lungs are left intact.

In reptiles, birds and mammals, the lungs have become their only organs of respiration, and have acquired a very large absorbing surface.

30. The structure of the respiratory organs

The respiratory tract. A human being breathes only through the lungs.

Before air that is inspired enters the lungs, it must pass through a long passageway. The respiratory tract begins with *the nasal cavity* (Fig. 65), separated from the mouth cavity by a partition, — at the front by a hard partition (*the hard palate*) and at the back by a soft partition (*the soft palate*). On the outer edge of the *nose openings* are little hairs that keep large particles of dust and other foreign particles from entering the nose. The nose cavity is divided into left and right halves by a compact partition. Arising from the outer side walls of each half of the nose cavity are *the nasal conchae*, which divide up the nose cavity into a series of narrow fissures, through which the inspired air passes (Fig. 66).

After passing through the nose cavity, the inspired air enters *the nasal part of the pharynx*, situated at the back. Its lower part (*the pharynx*) separates into two tubes: the one at the front is the windpipe, the one at the back is the oesophagus.

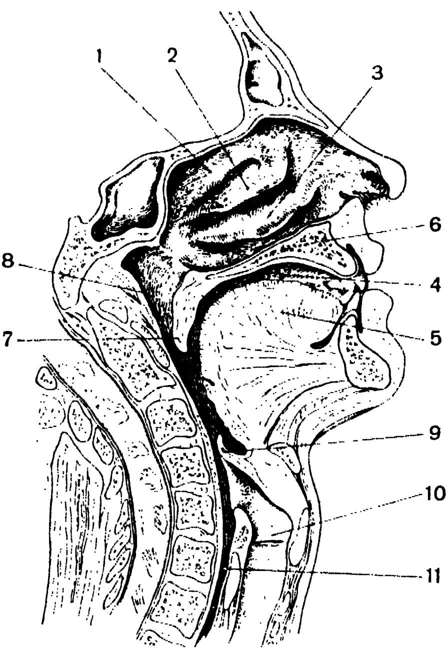

Fig. 65. Respiratory tract:

1, 2, 3 — nasal conchae; *4* — mouth cavity; *5* — tongue; *6* — hard palate; *7* — soft palate; *8* — nasal part of the pharynx; *9* — epiglottis; *10* — larynx (showing the vocal cords); *11* — oesophagus.

The upper part of the windpipe is called *the larynx*, or "*voice-box*" (Fig. 67). There are several movable articulations of cartilages in the walls of the larynx. The largest of them, *the thyroid* *cartilage*, projects over the front surface of the larynx; one can easily feel it in the neck. In the front part of the larynx, above the thyroid cartilage, is *the epiglottis*, which closes the entrance to the larynx when food is being swallowed.

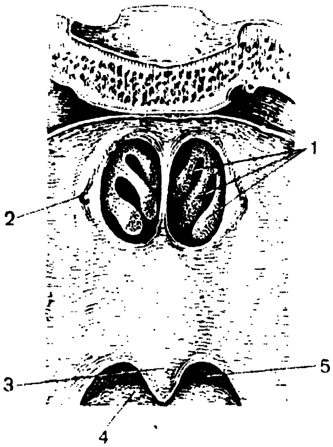

Fig. 66. Nasal cavity (as seen from the back — from the side of the nasal part of the pharynx):

1 — nasal conchae; *2* — opening of the canal leading to the cavity of the middle ear; *3* — uvula; *4* — posterior part of the back of the tongue; *5* — mouth cavity.

The voice apparatus. Inside the larynx are *the vocal cords* — two folds of mucous membrane, extending back from the front of the larynx. The passage between them is called *the glottis* (Fig. 68).

During normal respiration, the vocal cords relax, and the glottis is wide open. But if the vocal cords are tense and the glottis is narrowed, the outflowing stream of air passing through it sets the vocal cords in vibration. This, like the vibration of the strings of a piano, sets sound air waves into motion, and we hear sounds. The changes in the pitch of the human voice depend upon the thickness, length and tension of the vocal cords. Thus, the larynx is the voice organ. The cavity of the mouth, the tongue and the lips, together with the larynx, are of great importance in producing articulate human speech.

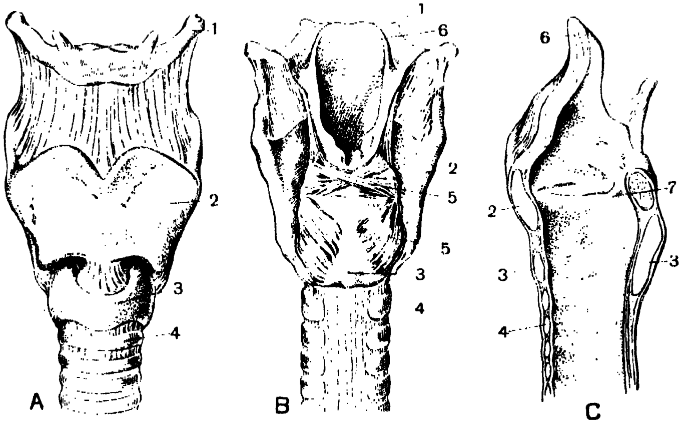

Fig. 67. Larynx: Front view *(A)*, back view *(B)*, cut open *(C)*:

1 — hyoid bone; *2* — thyroid cartilage; *3* — cricoid cartilage; *4* — tracheal cartilages; *5* — muscles of the larynx; *6* — epiglottis; *7* — vocal cords.

The trachea, or windpipe, and the bronchi. The respiratory tube that extends from the lower end of the larynx is called the trachea, or windpipe. The trachea divides into the two bronchi, one of which enters the right lung, and the other — the left (Fig. 69). In the lungs, the bronchi branch out over and over again. Half rings of cartilage are imbedded in the walls of the trachea and bronchi, making them elastic and preventing them from collapsing, and, at the same time, allowing the air to pass freely through them.

Mucous membrane. The respiratory tract is lined with mucous membrane. In the mucous membrane there are separate glandular cells, as well as whole groups of such cells, which form small glands continuously secreting mucus. Any microbes or small particles of dust, which find their way inside with the inspired air, are caught and held on the moist surface of the mucous membrane, to which they stick easily. As a result, the air passing through the respiratory tract is almost free of any suspended particles. Moreover, the mucus weakens the microbes, thus diminishing their ability to multiply and neutralizing their poisonous qualities; some of the microbes caught in the mucous membrane even die.

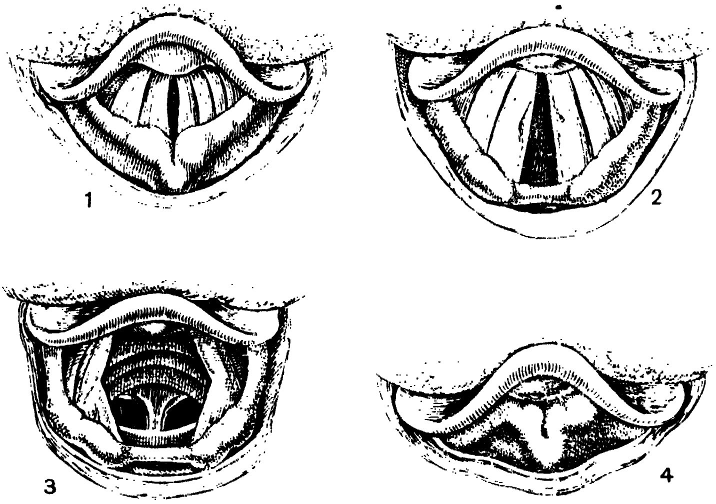

Fig. 68. Glottis (top view):

1 — when uttering a sound; 2 — when inhaling; 3 — when inhaling deeply (the division of the trachea into two bronchi is seen at the very back); 4 — reflex closing of the glottis when a strong smelling substance is brought to the nose.

White blood corpuscles, which seize and devour microbes, are continually passing from the blood vessels, through the intercellular interstices and spaces, to the surface of the mucous membrane. The mucus eliminated from the nose always contains a large number of dead leucocytes, or "pus corpuscles."

Most of the cells of the mucous membrane are supplied with a great number of hair-like projections called *cilia* (Fig. 70), which are in constant motion. Thus, the surface presents a wave-like appearance, which may be likened to the "waves" caused by

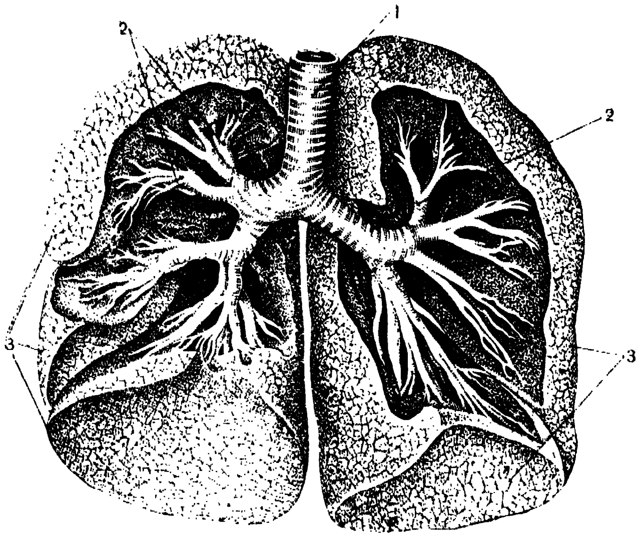

Fig. 69. Lungs (part of the lung tissue is removed to show the branching of the bronchi):

1 — trachea; *2* — bronchi; *3* — lungs.

wind over a wheat field. Each cilium bends quickly in the direction of the entrance and then slowly returns to its original position. By means of these movements, the cilia gradually push the mucus toward the exterior, and, together with the mucus, any particles of dust or other small bodies.

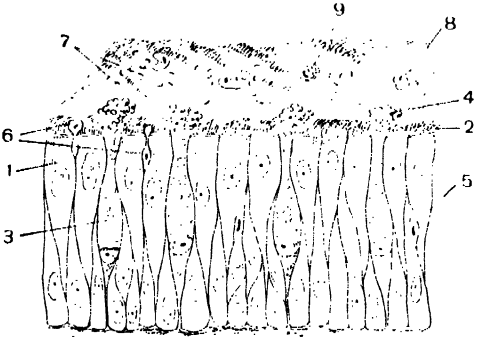

Fig. 70. Mucous membrane of the respiratory tract:

1 — cells with cilia (*2*); *3* — glandular cells secreting mucus (*4*); *5* and *6* — white corpuscles issuing onto the surface of the mucous membrane; *7* — microbes; *8* — a white corpuscle engulfing a microbe; *9* — a "pus corpuscle" (a dead white corpuscle).

The alveolar sacs of the lungs. Very minute bronchi that are no more than $^1/_2$ *mm* in diameter terminate in groups of alveolar sacs. When viewed from the outside, we see that the alveolar sacs are studded with half-circular little inflations which are hollow inside; these are so-called *alveoli*, or air-cells (Fig. 71). The walls of alveolar sacs consist of one layer of flat cells, wrapped round on the outside by a thick network of very minute blood vessels.

The interchange of gases between the blood and the air in the lungs is carried on in the alveolar sacs through the thin membrane that separates the blood from the air in the lungs; this membrane is formed by the walls of the alveolar sacs and of the blood vessels.

Due to the great number of alveolar sacs (there are about 3 million of them) and their cell-like structure, the internal surface space of the lungs is tremendous. If all the alveoli were flattened out, they would occupy an area of more than 100 *sq. m.* Such a vast surface of contact between the blood vessels and the air facilitates the interchange of gases.

The pleura. The inner surface of the thoracic cavity and the outer surface of each lung are covered by a smooth epithelial membrane — the pleura — that is always moist. At the point where the bronchi and blood vessels enter the lung, the pleura that covers the surface of the lung is reflected from the root of each lung to form the lining of the thoracic cavity. Consequently, each lung is enclosed on all sides by a bag, as it were, the walls of which are everywhere in such close contact with each other that there is no free space at all between them.

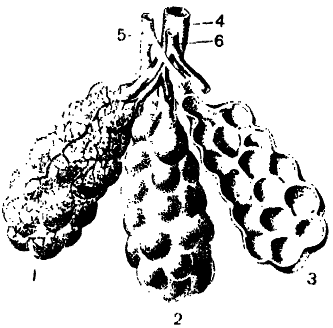

Fig. 71. Alveolar sacs:

1 — alveolar sac with a thick network of vessels; *2* — the vessels removed (showing the inflated air-cells); *3* — alveolar sac cut open (showing hollow air-cells); *4* — a very minute bronchus; *5* — a vein; *6* — an artery.

The location of the lungs in the thorax. The lungs occupy the whole cavity of the thorax, adhering firmly to its walls and leaving space only for the heart. Thus, the elastic tissue of the alveolar sacs are in a distended state. But if the thoracic cavity is cut open, much of the air is driven out of the lungs; as a result, the lungs collapse and occupy only a small part of the volume of the thoracic cavity.

The lungs in the body of the embryo, or of a newly born child, are in a completely collapsed state. But from the moment the child makes its first inspiration (or gives its first cry), the lungs fill up with air and, during the whole life of a person, remain in an inflated state, always adhering firmly to the walls of the thoracic cavity. This occurs because of the internal pressure of the air upon the walls of the lungs; on the outside, however, there is no such pressure, since the lungs are enclosed in a hermetically closed bag containing no air; this bag is formed by the two layers of the pleura, one of which has fused with the wall of the thoracic cavity and the other with the outer surface of the lungs. As a result of the pressure of the air inside the lungs, both layers of the pleura adhere firmly to each other.

31. The gaseous interchange in the lungs and in the tissues

The composition of inspired (or inhaled) and expired (or exhaled) air. If we compare the composition of the air expired by the lungs with the air of the atmosphere (Fig. 72), it is not difficult to see that an incessant interchange of gases goes on between the organism and its surrounding medium. The oxygen content in the air of the atmosphere may be as high as 21%, whereas the amount of carbon dioxide is not over several hundredths of one per cent. The amount of oxygen in the expired air is reduced to 16%; but, then, the carbon dioxide content is greatly increased, rising to 4% or 4½%. This is explained by the fact that the oxygen from the lungs enters the blood, and the carbon dioxide is eliminated from the blood into the air of the alveolar sacs.

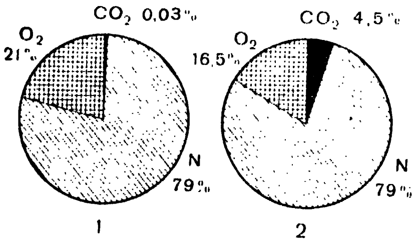

Fig. 72. Composition of (*1*) inspired and (*2*) expired air.

The gaseous interchange in the tissues. The blood flowing to the tissues of the body is saturated with oxygen, which, passing through the walls of the capillaries, enters the lymph and then the cells. In the cells of the body there are a number of specific ferments that take part in the various chemical processes. Particularly oxygen, which has made its way into the cells, is immediately acted upon by *the ferments* and unites with the different substances, oxidizing them. As a result of the oxidation processes, carbonic acid is formed, which passes into the surrounding lymph, and from there, through the walls of the blood vessels, into the blood.

The diffusion of gases. At the basis of the gaseous interchange described above is the property common to all gases — that of distributing themselves evenly over the space surrounding them. This phenomenon is called the diffusion of gases. The spreading of odoriferous substances may serve as an example of this. Thus, the smell of burnt food on the gas range does not remain in the kitchen, but gradually spreads throughout the apartment.

Diffusion of gases also takes place in liquids, or between a liquid and air. If a large quantity of some gas is present in a liquid, and if there is only a small quantity of it in the air, the gas will pass from the liquid into the air. This may be observed when a bottle of some effervescent drink, as kvass or soda water, is uncorked. The carbonic acid, of which there is a large quantity in the drink, begins to pass off in the form of bubbles. When there is more of any kind of a gas in the surrounding air than in a liquid, diffusion takes place in the reverse direction. If a glass of lime water is left in the room, the carbon dioxide of the air will pass into the liquid because of diffusion; the liquid will slowly grow turbid, due to the fact that calcium carbonate, an almost insoluble compound, has been formed in it.

The blood that flows to the lungs contains more carbon dioxide and less oxygen than the air in the lungs. Therefore, the oxygen of the air passes into the lungs, while the carbon dioxide passes out of the blood into the air.

According to the law of diffusion, it is clear that not only oxygen, but any gas contained in the air will pass into the blood. Therefore, nitrogen is always held in solution by the blood. But since nitrogen forms no compounds in the organism, and is neither expended nor absorbed, its content in the blood always remains unchanged.

The significance of hemoglobin. Arterial blood, coming from the lungs, contains a much greater amount of oxygen than it should contain according to the law of diffusion. This is accounted for by the fact that not all the oxygen that enters the blood remains in a free state; a large part of it immediately unites with the hemoglobin of the red blood corpuscles. To replace the oxygen that has united with the hemoglobin and has thus disappeared from the plasma, new supplies of oxygen from the air in the lungs pass into the blood. The slow movement of the blood in the pulmonary capillaries and the presence of hemoglobin in the blood provide for the absorption of great quantities of oxygen by the blood.

The saturation of hemoglobin with oxygen depends on the content of the latter in the surrounding medium, that is, in the plasma of the blood. When oxygen passes into the plasma of the blood and its content in the plasma is increased, the hemoglobin begins to draw it to itself. The greater the amount of oxygen held in solution by the plasma, the more fully does the hemoglobin of the red blood corpuscles become saturated with it. And, vice versa, in proportion as the amount of oxygen in the plasma is diminished, the compound of hemoglobin and oxygen breaks up and the liberated gas enters the plasma.

In the passage of the blood through the capillaries of the systemic circuit of the circulatory system, a considerable part of the oxygen, due to diffusion, passes out of the plasma into the tissue fluid, which contains scarcely any oxygen. As a result, the oxygen content of the plasma is reduced. The hemoglobin immediately begins to give up the oxygen with which it has combined; the oxygen now passes into the plasma and then into the tissue fluid.

Thus, the blood is an active carrier of oxygen, which it holds not only in the soluble state, but also in the form of an unstable chemical compound with hemoglobin.

The transport of carbonic acid by the blood. The content of carbonic acid in the blood is also greater than what might be expected on the basis of the law of diffusion. The blood transports large quantities of carbonic acid, since carbonic acid, like oxygen, enters the blood in chemical combination: the carbonic acid in the plasma forms a combination with sodium, and in the red corpuscles — with potassium.

Poisoning by charcoal fumes. One of the gases contained in the surrounding air is *carbon monoxide* (CO) — a gas of special importance. Carbon monoxide is the chief component part of charcoal fumes, produced when organic substances do not burn up completely. The hemoglobin of the red corpuscles combines readily with carbon monoxide to form a more stable compound than it forms with oxygen. When carbon monoxide from the air gets into the blood, it is immediately absorbed by the red corpuscles, thus freeing the liquid part of the blood for fresh supplies of carbon monoxide. As a result, diffusion does not cease; ever fresh supplies of carbon monoxide continue to pass into the blood and are snatched up by the erythrocytes each time. That is why even a small amount of charcoal fumes in the air will gradually form a large accumulation of it in the blood.

That part of the hemoglobin which combined with the carbon monoxide cannot unite oxygen to itself. Therefore, in a case of poisoning by charcoal fumes, the oxygen content in the blood is diminished, and, as a result, the normal oxidation processes in the organs of the body break down.

First aid in cases of poisoning by charcoal fumes. Poisoning by charcoal fumes occurs in everyday life when a stove is heated and the flue is closed before the wood has burned up completely. The symptoms of such poisoning are headache, shortness of breath, nausea, palpitation of the heart. Severe cases may bring about convulsions, loss of consciousness and even death. The first thing to do in rendering first aid is to carry the affected person out into the fresh air, and then to try to restore respiration by applying spirits of hartshorn to the nose, or by tickling the inside of the nose with a straw. If this does not help, *artificial breathing* should be used.

32. The respiratory movements

Pulmonary ventilation. The gaseous interchange between the air and the blood can take place only when the lungs are ventilated, which can be accomplished by means of respiratory movements. The contractions of the respiratory muscles bring about a change in the volume of the thoracic cavity. A change in the volume of the thoracic cavity is immediately followed by a change in the volume of the lungs.

When the thoracic cavity expands, the lungs become inflated and the outside air strives to get into them, just as the air is sucked into a pair of inflated bellows. When the volume of the thoracic cavity is reduced, the lungs become compressed and the excess of air in them is forced out. The alternate increase and decrease in volume of the thoracic cavity forces the air alternately into the lungs and out of them.

The change in volume of the thoracic cavity. The thoracic cavity may increase in length (from the top down) as well as in width (in circumference). The increase in length is caused by the contraction of the muscle in the partition between the thorax and the abdomen — *the diaphragm*. When this muscle contracts, it pulls the dome of the diaphragm downward and thus flattens it (Fig. 73).

The volume of the thoracic cavity depends not only upon the shape of the diaphragm, but also upon the position of the ribs. The ribs have their origin in the spinal column, and run in an oblique direction from the top down, turning first to the side and then to the front. The ribs have movable articulations with the vertebrae, and when the corresponding muscles contract, the ribs may rise and fall a little. When the ribs rise and pull the sternum upward and forward, the diameter of the thoracic cavity is increased; when the ribs fall, it is decreased (Fig. 73).

Normal, quiet respiration. When a person lies or sits quietly he makes 15 or 16 respiratory movements a minute. At each respiratory movement, a comparatively small part of the air in the lungs — about 500 *cu. cm.* of it, and often even less — is interchanged.

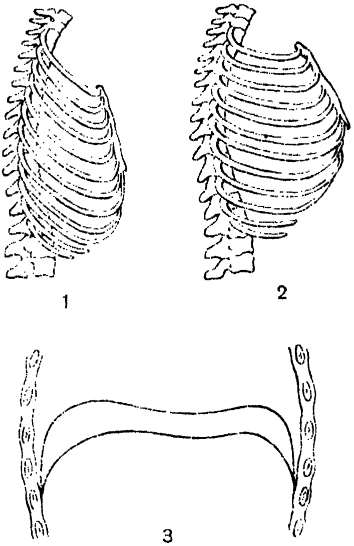

Fig. 73. Diagram of the change in size of the thorax:

1 — thorax when the ribs are lowered (expiration); *2* — thorax when the ribs are raised; *3* — position of the dome of the diaphragm in expiration (upper line) and in inspiration (lower line).

When air is *inspired* during such quiet, normal respiration, the muscles of the diaphragm contract, and its dome becomes more flat. The inspiratory muscles, situated between the ribs and also between the ribs and the vertebrae, contract simultaneously. When this happens, the ribs are raised, thus stretching the cartilages that connect the ribs with the sternum. As soon as the inspiratory muscles stop contracting, the rib cartilages that have been pulled upward return to their normal position, and in so doing, lower the ribs; at the same time, the diaphragm bulges out at the top due to the pressure exerted by the abdominal organs.

In quiet respiration, therefore, the muscles contract only at *inspiration* (or *inhalation*). *Expiration* (or *exhalation*) proceeds passively — as a result of the relaxation of the muscles.

Deep breathing. Pulmonary ventilation may be greatly increased by deep breathing, which intensifies both inspiration and expiration.

By intensifying inspiration, we may draw about 1500 to 2000 additional cubic centimetres of air into the lungs. Deep breathing is accomplished not only with the help of the above mentioned muscles, but also with the help of a number of other muscles (for example, the muscles extending to the ribs from the shoulder-blade and from the humerus, and also the muscles of the neck).

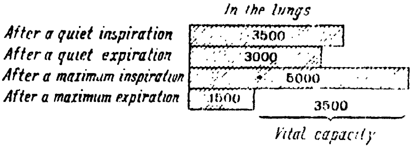
In the lungs
After a quiet inspiration
3500
After a quiet expiration
3000
After a maximum inspiration
6000
After a maximum expiration
1500
3500
Vital capacity

Fig. 74. Change in lung capacity during quiet and during deep breathing.

At the end of a quiet expiration, it is possible for a person to expel about 1000 to 1500 more cubic centimetres of air. During such expiration, the diaphragm becomes more convex than usual and the ribs are drawn downward with force. This is caused by the contraction of the intercostal expiratory muscles and also of other expiratory muscles, chiefly of the abdominal muscles, that is, the muscles of the walls of the stomach. The abdominal muscles are attached by their upper ends to the lower edge of the thorax. In contracting, they draw the thoracic cavity down and press against the cavity of the stomach (the stomach is "drawn in"), forcing the diaphragm to bulge out still more in the thoracic cavity.

The vital capacity of the lungs. A change in the volume of the thoracic cavity depends on the depth of the breathing (Fig. 74). In quiet breathing, the thoracic cavity changes very little in volume; in deep breathing, a person can draw several litres of air into the lungs.

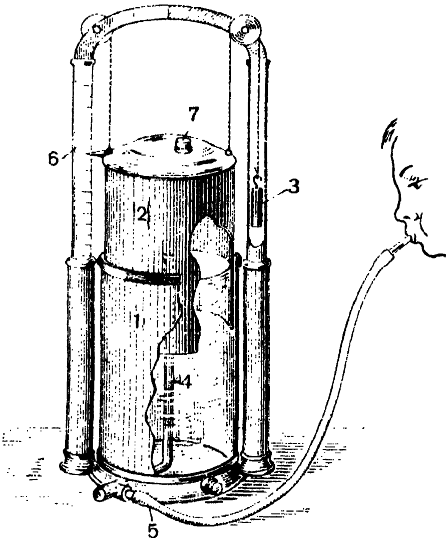

Fig. 75. Spirometre:

1 — outer cylinder filled with water; *2* — second cylinder within the outer one; *3* — load counterbalancing the inner cylinder (2); *4* — tube through which the expired air gets into the spirometre (the end of the tube within the cylinder is above the level of the water); *5* — rubber tube with a mouthpiece; *6* — scale to determine the volume of air expelled into the spirometre; *7* — plug.

The quantity of air which one can inspire at the end of the deepest expiration (or, on the contrary, the quantity which one can expire after the deepest inspiration) is known as the vital capacity of the lungs. A spirometre — the apparatus illustrated in figure 75 — is used to determine the vital capacity of the lungs.

Investigations made with the help of the spirometre have shown that the vital capacity of the lungs differs in different people. It usually varies from 3000 to 5000 *cu. cm.*

The importance of deep breathing. After a normal expiration, about 2500 *cu. cm.* of air remain in the lungs. During a normal inspiration, a person draws in about 500 more cubic centimetres of air, of which only 300 to 350 *cu. cm.* reach the alveolar sacs, since at least 150 *cu. cm.* remain in the respiratory tract (the nasal part of the pharynx, the larynx, the trachea and the bronchi). Thus, in quiet inspiration, only about 350 *cu. cm.* of the outside air get into the alveolar sacs; this constitutes not more than $^1/_7$ of the amount of air in the alveolar sacs.

Such pulmonary ventilation is by far not always sufficient. Work, especially that which is connected with a great expenditure of energy, greatly intensifies the processes of decomposition and oxidation in the organism; consequently, the need for oxygen and the production of carbonic acid are also increased. Under such conditions, pulmonary ventilation is considerably increased; at each inspiration, $^1/_4$ and even $^1/_2$ of the air in the lungs is interchanged, and not $^1/_7$.

Pulmonary ventilation may be increased by *accelerating* respiration, as well as by *intensifying* each respiratory movement. When there is too great an acceleration — from 40 to 50 inspirations per minute — the breathing becomes so shallow that only a small portion of air enters the alveolar sacs. As a result, there is insufficient ventilation of the lungs, and the gaseous interchange between the pulmonary air and the blood proceeds weakly. Deep breathing, on the other hand, best provides for the ventilation of the air in the lungs, and helps to intensify the gaseous interchange.

Artificial breathing. If the respiratory movements cease, they may be restored artificially. Artificial breathing is used in cases of drowning, of shocks produced by an electric current, etc. Artificial breathing is the alternate expansion and contraction of the thorax by some outside force (Fig. 76). The person who is rendering first aid takes a position at the head of the patient; he then draws the patient's arms upward and backward as far as they can go. The movement of the arms raises the ribs, the thorax expands and air is drawn into the lungs. Then the arms of the patient are bent at the elbows at a sharp angle and pressed close to the chest, thus pressing against the ribs. As a result, the ribs are lowered, the thorax is compressed and air is expelled from the lungs. The rhythm of artificial breathing should be the same as in natural breathing — 16 respiratory movements per minute.

Artificial breathing should be continued without a stoppage as long as there is evidence of even the slightest activity of the heart. There have been cases when a person was brought back to life even several hours after natural breathing had stopped.

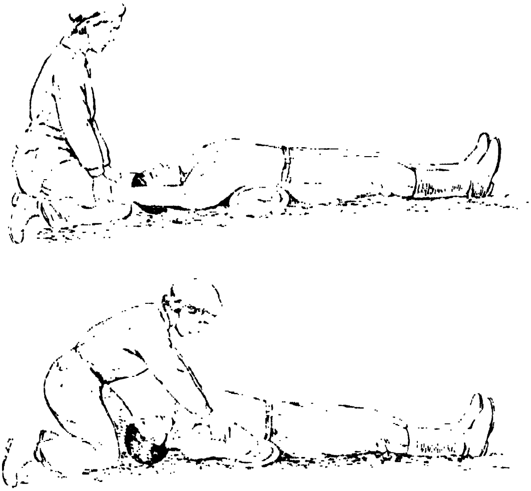

Fig. 76. Artificial respiration: at the top — position of the patient to induce inspiration; at the bottom — position of the patient to induce expiration.

Problem. Place your hand on your chest and count the number of respirations per minute. Knowing the volume of air expelled with each normal expiration, and knowing the content of carbon dioxide in it, figure out the amount of carbon dioxide, in volume, which you expel every hour, every day.

33. The regulation of respiration

The respiratory centre. The respiratory centre — a part of the central nervous system, is located in the lower part of the brain, in the medulla oblongata. If the respiratory centre is destroyed, respiration ceases immediately.

Impulses travel from the respiratory centre, along the nerve fibres, through the spinal cord, and reach the respiratory muscles. When this occurs, the inspiratory and expiratory muscles are stimulated in a strictly definite order, first one and then the other.

The reflex self-regulation of the respiratory movements. The branches of *the vagus* (already known to us), which are composed of afferent nerve fibres, lead to the lungs (Fig. 77). The endings of some of the afferent fibres are excited when the lung tissue expands (in other words, at inspiration). The impulses that are aroused travel to the respiratory centre, bringing about the reflex relaxation of the inspiratory muscles. As a result, the thorax decreases in volume and an expiration follows.

Other afferent fibres of the vagus nerve are excited at expiration, and, through the respiratory centre, bring about the reflex contraction of the inspiratory muscles.

This is the way in which the self-regulation of the respiratory movements goes on reflexly: inspiration brings about expiration, and expiration brings about inspiration.

The reflex changes in the respiratory movements. The character of the respiratory movements may change in response to irritation of the skin and of other parts of the body. Thus, the temporary suspension of respiration, which occurs at a sudden dash into cold water, is due to the irritation of the endings of the afferent nerves in the skin.

Of great importance is the reflex strengthening or weakening of the respiratory movements, called forth by the irritation of the nerve endings located in the walls of the blood vessels and, especially, by the nerve endings located at the point where the carotid artery begins to branch outward and inward, forming the outer and inner carotid arteries (Fig. 77). Some nerve endings are brought to a state of excitation when a blood vessel dilates (that is, when the blood pressure is increased), as a result of which respiration is reflexly suspended. Other nerve endings, sensitive to chemical stimuli, are brought to a state of excitation when the content of carbonic acid in the blood is increased. In such a case, respiration is intensified and its frequency increased reflexly.

Protective reflexes. Irritation of the mucous membrane of the respiratory tract brings about reflex actions of a protective character. Thus, when a piece of cotton wool, soaked in liquid ammonia, is brought close to the nose, the endings of the olfactory nerve are irritated; the result is a reflex *suspension of respiration;* at the same time the glottis closes (Fig. 68, *4*), and thus harmful substances cannot get into the organs of respiration. A weaker irritation of the mucous membrane of the nose causes *sneezing.* Irritating substances that find their way to the mucous membrane of the larynx, the trachea, or the bronchi, cause reflex *coughing.*

Just before sneezing and also before coughing, one takes a preliminary deep breath; the glottis closes and the expiratory muscles contract; as a result of the muscle contraction, the air inside the lungs is compressed, the glottis immediately opens wide and the compressed air rushes out with force. In sneezing, the air passes out through the nose, and in coughing — through the mouth.

Sneezing and coughing help the respiratory tract to get rid of any irritating substances that have made their way inside the tract.

The role of the cortex of the cerebral hemispheres. Respiratory movements may take place without the participation of the cortex of the cerebral hemispheres. Nevertheless, the cortex always influences respiration by sending impulses to the respiratory centre. As a proof of this is our ability to change the frequency and force of the respiratory movements at will: for example, while talking.

Those changes in respiration which are characteristic of laughter and crying are also connected with the influence exerted by the cerebral cortex. When a person *laughs*, the glottis opens and closes alternately at the time of expiration; when a person *cries* (sobs), the glottis opens and closes in exactly the same way, but it does so now at the time of inspiration.

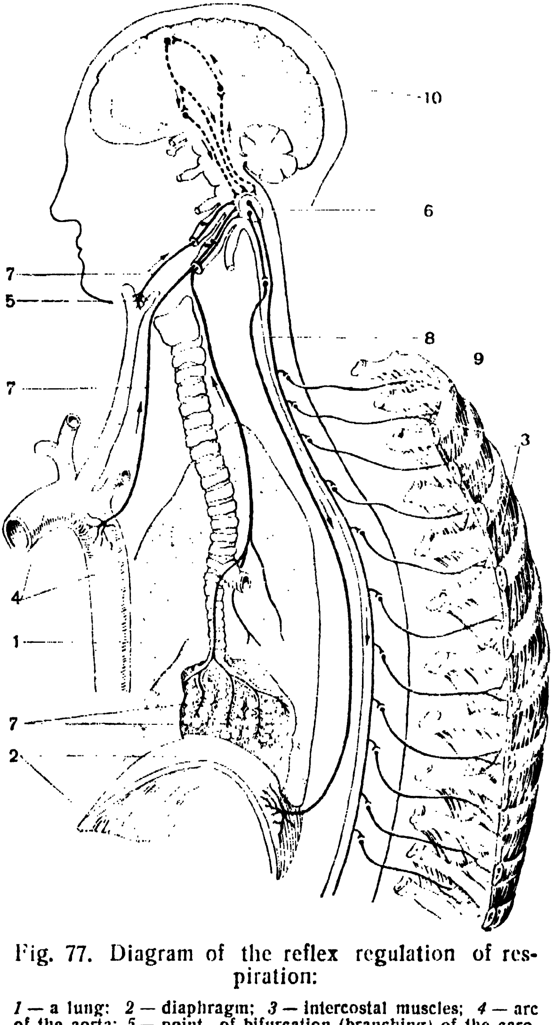

Fig. 77. Diagram of the reflex regulation of respiration:

1 — a lung; *2* — diaphragm; *3* — intercostal muscles; *4* — arc of the aorta; *5* — point of bifurcation (branching) of the carotid artery; *6* — respiratory centres in the medulla oblongata; *7* — afferent nerve fibres coming from the lung tissue, the aorta and the point of bifurcation of the carotid artery; *8* — efferent fibres going to the diaphragm and *9* — to the intercostal muscles; *10* — afferent and efferent paths which connect the respiratory centre with the cortex of the cerebral hemispheres.

The influence of carbonic acid on the respiratory centre. The excitability of the respiratory centre and, consequently, the frequency and depth of respiratory movements, depend upon the action, on the respiratory centre, of chemical stimuli found in the blood, especially of carbonic acid; this can easily be observed in an experiment performed on two dogs with crossed circulations.

The carotid arteries, carrying blood to the head, and *the jugular veins*, carrying blood from the head to the heart, are cut on one side of the neck of each dog. The cut ends of the arteries of both dogs are connected by a tube in such a way that there is an exchange of blood — the blood of each dog passes into the carotid artery of the other (Fig. 78). If the uncut carotid artery and jugular vein on the other side of the neck of each dog is compressed, the brain of each dog will receive the blood of the other dog, but not its own blood. If, now, the trachea of one of the dogs is compressed, thus shutting off the ventilation of the air in the lungs, the respiratory movements of the other dog will increase in frequency and depth.

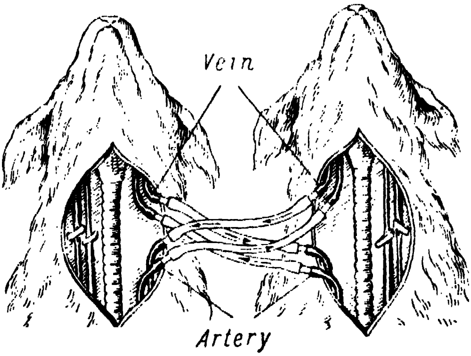

Fig. 78. Experiment with crossed circulations.

This can be explained by the fact that the excitability of the respiratory centre depends, to a great extent, upon the composition of the blood flowing through it.

In cases of greatly intensified work, or in cases of suffocation, carbonic acid accumulates in the blood and excites the respiratory centre; as a result, the respiratory movements become deeper and occur more frequently. On the other hand, if the content of carbonic acid in the blood is diminished, the excitability of the respiratory centre is reduced, and respiration becomes weaker and less frequent. Thus, the content of carbonic acid in the blood plays an essential role in the regulation of the respiratory movements.

Questions. 1. Why do divers take several deep breaths before diving? Of what importance may this be?

2. Explain why the first respiratory movements appear in a newly-born child only after its umbilical cord has been cut.

Problem. Put a watch that has a second-hand on the table; then take a deep breath, and hold the breath. How many seconds were you able to hold your breath? What were the respiratory movements like the moment you released the breath (deep or shallow)? Take several deep and rapid breaths and watch whether the respiratory movements do not cease for some time after that.

Write the results of your observations, with a detailed explanation, in your copy-book.

34. The hygiene of respiration

The importance of correct breathing. Correct breathing helps to improve the health and to raise the working capacity. One of the principal conditions of correct breathing is the care taken to develop the thorax, which may be achieved by maintaining correct posture when standing, walking and sitting, by doing morning setting-up exercises daily, and by gymnastics and sport. As a rule, a person who has a well-developed thorax breathes evenly, rhythmically. Frequent, uneven respiration prevents productive mental work; whereas normal, quiet respiration, on the contrary, helps one to concentrate on one's work.

Normal rhythm in respiration can be maintained only by breathing through the nose. However, the importance of breathing through the nose does not end here. In passing through the narrow fissures of the nasal cavity, the inspired air is warmed up and rids itself of particles of dust and of microbes.

The influence of the surrounding air on the organism. Fresh outdoor air has a favourable effect on the organism. The air in close, unventilated rooms is harmful. Such air contains vapours, carbon dioxide and ill smelling substances, produced when perspiration decomposes. In addition to these, there may also be dust particles and various gaseous substances, which are given off, for example, in cooking.

People who spend much of their time in poorly ventilated rooms, and spend little time out of doors, become anaemic and lifeless; they tire easily and suffer from headaches.

The contraction of contagious diseases from the air. The air may be a means of spreading certain diseases. When a sick person coughs, sneezes, speaks and even exhales violently, little droplets, in which there may be microbes of various contagious diseases, are expelled into the air. Such droplets usually remain in the air for a greater or lesser period of time and readily find their way into the respiratory organs of other people nearby. The grippe, diphtheria, the whooping-cough, the measles, scarlet fever and some other diseases may be contracted in this way. This method of infection is called *droplet infection.*

Dust is also a carrier of contagious diseases. In cleaning up a room or brushing clothes, particles of dried up saliva, phlegm, pus, in the form of very minute specks of dust, get into the air and do not settle for a long time. Some contagious diseases (for example, tuberculosis) are easily contracted by means of such infected dust particles. Such an infection is called *dust infection.*

People who spend much of their time in close rooms run the risk of dust infection, and especially of droplet infection. Outdoor air, which is in constant motion, quickly carries off and scatters the microbes which get into it.

Ventilation at one's home and at one's place of work. All this means that it is not only necessary to be out in the fresh air often, but that it is just as important to have pure air in one's room.

The less air there is in a room, the more quickly the air spoils; the more there is of it, the longer it retains its normal properties. Therefore, there should not be too much furniture in a room.

The air in rooms should be constantly renewed. To provide for a constant change of air, special ventilation systems are installed in places where many people gather (theatres, clubs), or in places where the air is especially liable to be filled with injurious gases and a great quantity of dust (as in some factories and plants).

One's room should be regularly aired in the morning after getting up, and in the evening before going to bed. It is still better to sleep with one's window open.

The fight against dust. In the fight for wholesome air, it is as necessary to get rid of dust as it is to air one's room. Before entering a room, one must carefully scrape the dirt off one's shoes, so as to avoid carrying dust from the street into the room; one should never enter a room with one's coat on, nor should one brush one's clothes or boots in one's room.

In cleaning a room, one should try not to raise dust. The floor should be swept with a damp broom or with a brush wrapped round with a damp rag; dust from furniture or other things should also be wiped off with a damp rag.

The importance of social sanatory measures. The fight for wholesome air should not be limited only to those measures which a person can put into effect in his own room. Social sanatory measures are also necessary.

In the Soviet Union such measures are a matter of state concern. The planting of trees in towns and in workers' settlements, the creation of a "green defensive zone" round separate buildings, blocks and whole cities, the watering of streets, the construction of special smoke retainers in the chimneys of factories, works, etc., are social sanatory measures.

35. Tuberculosis and the fight against it

Tuberculosis — an infectious disease. Tuberculosis is one of the most widely spread of infectious diseases. In capitalist countries it is mainly the working population that suffers from tuberculosis: in the workers' quarters of London, New York, Paris and other industrial cities, the number of tuberculosis cases is six to seven times greater than in those districts where the bourgeoisie lives. The enslaved peoples of colonial countries especially suffer from tuberculosis. In the U. S. A. the death-rate among Negroes as a result of tuberculosis is many times greater than that among the white people; this is due to the semi-state of bondage in which the Negro population finds itself.

Tuberculosis is caused by a microbe that resembles a slender, microscopically minute rod. These *tubercle bacilli* are capable of multiplying very quickly within the human organism. They do not multiply outside the organism; however, given conditions of warmth and dampness, they can remain alive and active for weeks and even for months. Sunlight kills them in the course of a few hours, and sometimes even after several moments. They are also killed by boiling.

Forms of tuberculosis. Tubercle bacilli that get into the human organism are capable of bringing about changes in the different organs, and may even cause their destruction. Around the microbes appear zones of inflammation, resembling small *elevations*, or *tubercles* (the Latin term, from which is derived the name of the disease — tuberculosis). Separate tubercles sometimes fuse together and then much larger affected areas are formed.

When dissecting and studying corpses, such tubercles have been found in almost all adults, even in adults who were never ill with tuberculosis. These observations have shown that tubercle bacilli can make their way into the organism very easily, but, in many cases, the organism fights with and overcomes them quickly; thus, the disease is checked in its initial stage, and remains unnoticed. The success of the struggle of the human organism against infection depends upon the general state of the organism, which, as we have already pointed out, is determined, to a great extent, by *the nervous system*. An incorrect mode of life, over-exertion, extreme fatigue, starvation, and other causes which weaken the organism, lower the power of resistance of the organism to the harmful action of microbes and, as a result, tuberculosis develops.

In most cases, tuberculosis affects *the lungs*. The first symptoms of this disease are usually the tendency to become quickly fatigued, a poor appetite, loss of weight, a light cough, sweating, and a slight rise in the temperature. In severe cases, there is continual and painful coughing, and a steady and rapid loss of weight (the patient, so to say, is being consumed; from this comes the popular name of "consumption").

Children often suffer from tuberculosis of *the spinal column* and of *the joints*. An affected spinal column often leads to curvature of the spine and to the formation of a hump, if the proper treatment is not given in time. In cases of tuberculosis of the hip joint or of the knee joint, the patient may be lamed for life, if proper treatment is neglected.

Lupus, which usually affects the skin of the face, and tubercular diseases of some of the other organs, are also most prevalent among children.

Tuberculosis of the membranes of the brain, or meningitis (*tubercular meningitis*) is a most noxious disease.

The treatment and cure of tuberculosis. Even severe forms of tuberculosis can be cured. The detection of the disease in its early stages is a necessary condition for the successful treatment of the disease. At the first symptoms of any chronic ailment, therefore, a doctor should be consulted at once. No symptoms of this disease should be neglected, no matter how slight these symptoms might appear to be: a bad appetite, general lassitude, the tendency to tire easily, a rise in the temperature, even if only a slight one, pain in the knee joint or in other skeletal parts of the body.

A method of great importance in determining the presence of tuberculosis, especially in children, is the injection in the skin of a small amount of *an extract of tubercle bacilli*; if there is an infection, a redness and a swelling will appear on the spot where the extract was injected. If a person is suspected of having tuberculosis, he is sent to a tubercular dispensary for a correct diagnosis of the disease and for treatment.

In the treatment of tuberculosis, the principal aim is to strengthen the organism, so that it will be able to struggle with the disease and overcome it. Therefore, the first thing to do is to observe the fundamental rules of a hygienic regime. The most important of these are: plenty of fresh air and outdoor activity, especially in connection with physical labour, ventilation of one's room, plenty of sleep with the window open, gymnastics, walks, (in winter — skating and skiing), proper food, and regular meal hours. Patients suffering from tuberculosis must absolutely abstain from smoking and from alcoholic drinks. In the Soviet Union, a great number of special sanatoriums have been built, where a well-planned hygienic regime for the patients enables them to strengthen and harden their organism.

There are also other methods of treating tuberculosis. Thus, for example, in the case of pulmonary tuberculosis, air is insufflated into the cavity of the pleura (pneumothorax). As a result, the part of the lung being insufflated is compressed, which helps to heal the tubercular zone. With the same purpose in view, tuberculosis of the bones and of the joints is treated by means of plaster of Paris bandages, corsets and splints, so as to provide the maximum amount of rest for the affected organs.

Within the last few years our native industry has mastered the method of producing *streptomitzin*, which checks the growth and the reproduction of tubercle bacilli. Streptomitzin gives excellent results in the treatment of some forms of tuberculosis. Its action has been found to be especially favourable in the case of tubercular meningitis, which was considered incurable not so long ago.

Measures for preventing tuberculosis infection. Tuberculosis may be contracted by direct contact with the source of infection. Thus, for example, a person may be infected by using the dishes, the towel or the handkerchief of a tubercular patient or by inspiring air (in the form of droplet and especially dust infection) contaminated by a tubercular patient.

In order to prevent infection, a struggle must be waged against dust and also against the carriers of infection — flies; it is no less necessary to maintain perfect cleanliness of one's body, one's clothes, one's room and one's place of work. Since sputum is the main source of infection, it is of the greatest importance that a tubercular patient should collect his sputum in special, closed spittoons, that he should cover his mouth with a handkerchief when sneezing and coughing, that he should always have a separate bed, towel and separate dishes, and that he should never kiss children, nor take them in his arms.

In the struggle against infection, a most important factor is the general strengthening of the organism; this may be achieved with the help of proper physical training and a proper regime of work and of rest.

Protective inoculations, which serve to create active immunity to tuberculosis, are widely used in our country. Cases of tuberculosis among inoculated children are much rarer than among those who are not inoculated. And even if inoculated children contract the disease, they get it in a very mild form, which is usually curable. In order to maintain immunity, it is necessary to repeat the inoculations every 2—3 years.

The struggle against tuberculosis in the U.S.S.R. During the first ten years following the Great October Socialist Revolution the death-rate of tuberculosis in our country — in such large cities as Moscow and Leningrad — was cut down to less than half of what it was before. This came as the result of the sanatory improvements in the living and working conditions of the population. The further rise in the standard of living of the toiling masses, and also the introduction of special measures, as, for example, periodical examination of the population in order to detect the disease in the early stage, the establishment of a wide network of tubercular dispensaries, sanatoriums, and the organization of protective inoculations for all the people, are reducing the death-rate of tuberculosis from year to year.

The abolition of capitalist exploitation and the successful building of communism have provided for a steady rise in the material and cultural standard of living of the working masses, and have made it possible for our Party and Government to carry out sanatory measures on a large scale; in these ways, the prerequisites have been created for the liquidation of tuberculosis as a mass disease in the U.S.S.R.

REVIEW QUESTIONS

1. In what part of the organism do the oxidation processes go on?
2. Why are the lungs in an inflated condition? Under what conditions may the lungs become deflated?
3. What is the structure of the respiratory tracts and of the lungs?
4. Why must we breathe through the nose and not through the mouth?
5. How does inspired air differ from expired air?
6. Describe the process of the interchange of gases between the organism and the environment.
7. What happens in the organism of a person who is poisoned by charcoal fumes?
8. What are the chief rules for the rendering of first aid in a case of poisoning by charcoal fumes?
9. Describe inspiration and expiration under conditions of normal (quiet) and of deep respiration.
10. What is the vital capacity of the lungs and how is it measured?
11. What first aid should be rendered when respiration ceases?
12. How does pulmonary ventilation change with the changes in the activity of the organism?
13. How are the movements of respiration regulated?
14. What are the chief rules of the hygiene of respiration?
15. How is it possible to safeguard oneself against tuberculosis?

V. THE ORGANS OF DIGESTION

36. Food and its composition

The importance of nutrition. As we know, vast numbers of red corpuscles decompose and die in the organism daily. Other cells of the body decay and die also. However, these are not the only processes of disintegration that go on in the organism. Metabolism and the release of energy necessary for the vital activity of the organism are connected with the process of the decomposition, which goes on unceasingly in each cell, of a part of the cellular substance.

What the organism loses is continually being restored by the food consumed by the organism daily. From food the organism obtains the substances which it needs for the production of new cells to replace those that died, and also for growth and for the compensation of losses connected with the vital activity of the cells. If an animal is deprived of food, it loses weight quickly and finally dies of emaciation.

Thus, food is *building material* for the organism, and at the same time constitutes its only *source of energy*.

Nutritive materials. Constituents of food which are necessary for the organism are called nutritive materials. The most important nutritive materials are three groups of complex organic compounds which enter into the composition of living matter, namely: *proteins*, *fats* and *carbo-hydrates*.

Food also contains various *mineral substances* (sodium chloride, calcium chloride, and other inorganic salts), water, and also a small amount of specific substances (*vitamins*), which are of vast importance for the processes of metabolism that go on in the organism.

Foods. Proteins, fats and carbo-hydrates enter into the composition of various foods. Certain foods consist almost exclusively of a single nutritive material. Thus, for example, sugar is a pure carbo-hydrate, while sunflower oil is a fat with a very small admixture of other substances. However, the vast majority of foods are composed of different nutritive materials in varying quantities.

For a correct and intelligent approach to the question of nutrition, it is necessary to have a notion of the content of proteins, fats and carbo-hydrates in various foods. In spite of the great variety of their composition, all foods fall into several main groups.[1]

1. Meat and fish products. Meat and fish are some of the main sources of protein: ordinarily, they contain 15% to 20% of protein. Caviar contains an especially large amount of protein (from 20% to 30%). The amount of carbo-hydrates contained is very small (usually not more than 0,5%). The fat content may vary: lean beef — from 3% to 5%; very fat beef — as much as 25% and even more.

Veal, chicken, carp, crucian, sander, pike, and others are examples of lean products of this group; pork, mutton, herring, burbot, salmon, beluga, and most kinds of sausage contain a large proportion of fat.

2. Eggs. Eggs are rich in protein (14%) and fat (11%); they contain almost no carbo-hydrates. The most nourishing part of the egg is the yolk, which contains about 30% of fat and of other materials necessary for the organism.

3. Milk and milk products. Milk contains very much water. The content of nutritive material in milk is 3,5% each of protein and fat, and 5% of carbo-hydrates.

When milk stands for some time, the fat rises to the top, forming a layer of cream. Skimmed milk contains practically no fat. If milk is left to stand for a long time, and also under other conditions (for example, when it turns sour), it curdles, forming a solid mass or sediment of protein, called casein. Milk products rich in protein (curds, cheese) are prepared from curdled milk. The content of fat in them depends upon the method of preparation: products that contain almost no fat are obtained from skimmed milk; the products made from cream have a high fat content.

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[1] The composition of various foods is given in the tables at the back of the book.

4. Animal and vegetable fats and oils. The foods of this group contain hardly any carbo-hydrates or proteins, and sometimes none at all. Many fats are prepared by special methods out of animal and vegetable foods: butter is obtained by churning cream or sour cream; oil is pressed out of seeds; margarine is a special fat preparation.

5. Vegetables, fruit, berries, mushrooms. Like milk, these foods contain very much water. The amount of carbo-hydrates varies from 20% (in potatoes) to 1% or 2% (in lettuce, cucumbers). This group rarely contains more than 1% to 2% of protein. The fat content is very low.

6. Cereals and flour. Cereals and flour contain very little water. In an ordinary diet it is these foods that are our main source of carbo-hydrates, since they contain from 50% to 70% of starch. These grain products, together with meat and fish, supply us with much protein (they contain, on the average, about 10%). The fat content is very low.

A large quantity of water is added in preparing food made of cereals or flour: bread weighs 30% to 50% more than the flour used in its preparation; in cooking gruel, 3 to 5 times and even 10 times more water is used than cereal.

7. The fruits of leguminous plants. Peas, beans, kidney beans, soya beans and lentils are especially rich in protein (28% to 30%); they also contain a large proportion of carbo-hydrates. Soya beans, which make up the principal diet in some localities, contain much fat.

8. Nuts. Not all kinds of nuts have the same proportions of nutritive material. However, all of them are rich in fat; the fat content of some kinds of nuts is 60% and more. Moreover, there is much protein in nuts (about 15%). The carbo-hydrate content is low.

Sunflower seeds have about the same composition as nuts: their fat content is 40% to 50%.

9. Sugars. Sugar is a pure carbo-hydrate. Honey, fruit and berry jam, sugar-candy, caramel, and many other kinds of sweets are also practically pure carbo-hydrates, if we do not take into consideration water and a very small quantity of protein and other materials which they contain.

Starch, obtained from potatoes or flour, also belongs to this group; starch, like sugar, is a pure carbo-hydrate.

10. Chocolate, cocoa. These foods contain a great amount of carbo-hydrates (from 50% to 70%), and also a large proportion of fat (about 20%) and about 5% of protein.

Problem. Write down in your copy-book three types of food (taken from your daily diet) for each of the nutritive materials: proteins, fats, carbo-hydrates. See that the foods chosen are the main sources of these three constituents of food. Which of the foods you have listed are simultaneously the source of two groups of nutritive materials? Of which nutritive materials?

37. Digestion

The importance of digestion. Certain animals obtain their nutritive material from the surrounding medium already prepared, and not requiring any preliminary preparation. Intestinal worms and some other kinds of parasites are animals of this type. They live in the intestines or in some other organ of their "master," and thus receive nutritive material that is already prepared and digested.

The great majority of animals, however, feed on nutritive materials that cannot force their way through the membrane of the cells and which, therefore, cannot be assimilated by the organism. In order to be assimilated, the nutritive material must first be reduced to simpler forms. During the process of reduction, mechanical and chemical changes take place in the food.

The mechanical change consists in breaking up the food into small pieces with the teeth, and also in moistening it. The food, in a finely divided up and soluble state, is more easily subjected to chemical *changes*, which consist in splitting up the complex particles of proteins, fats and carbo-hydrates. By this process of splitting up or separation — digestion, in which digestive *ferments* take part — the nutritive material is reduced to less complex substances, which can then pass freely through the walls of the intestines.

The splitting up of carbo-hydrates. In the process of digestion, each molecule of starch is split up into several molecules of simple carbo-hydrates — *grape sugar*, or *glucose*. A molecule of cane or beet sugar (material which is constantly used in our food) is split up into two particles of simple carbo-hydrates — glucose and *fruit sugar*. Milk sugar, which is one of the constituents of milk, is also split up into two particles of simple carbo-hydrates.

The splitting up of proteins. Proteins do not split up immediately. The first results of the process of separation is the formation of substances that are still very complex; these substances are then split up again and again until they are reduced to more simple compounds — *amino-acids*.

At the present time, more than 20 different kinds of amino-acids are known that enter into the composition of proteins. The proteins of various animals and plants, and also the proteins of the various organs and tissues of the body, contain varying quantities of the different kinds of amino-acids.

The splitting up of fats. One molecule of fat is split up into one molecule of *glycerol*, known to all of us, and into three molecules of *fatty acids*.

Fatty acids combine with alkalis to form salts called *soaps*. Ordinary household soap is a sodium salt of fatty acids and is obtained by the action of caustic soda on the fatty acids.

Digestion inside the cell. In one-celled animals, digestion takes place within the cell. If we watch, through the microscope, the movements of an amoeba, we may see it thrust out little projections — pseudopods, from one part of its body or another. If the body of the amoeba comes in contact with some solid particle, the pseudopods seize upon it, flow over and around it, as it were, and very soon the particle is inside the body of the amoeba. A little cavity, called the food vacuole, is formed in the protoplasm surrounding the particle. The digestion of the nutritive material, contained in the captured particle, takes place with the help of digestive ferments, or enzymes, which have forced their way into the vacuole from the protoplasm. The indigestible remains are eliminated to the exterior at the moment when the vacuole, as a result of the movements of the amoeba, is on the very surface of its body.

Digestion outside the cell. The following experiment was performed on some large coelenterata (sea-anemones). Some pieces of blood protein — fibrin, wrapped up in filter paper, were introduced into the digestive cavity of these animals. After some time, the fibrin was withdrawn and examined. The fibrin was found to be almost entirely dissolved. This experiment shows that digestion in sea-anemones may proceed, not within the cells, but in the digestive cavity itself, where the particles of food stick to the mucus secreted by specific glandular cells. This mucus contains ferments, thanks to which the food is digested. Small, half-digested particles may be engulfed by other cells, within which, as in the body of the amoeba, food vacuoles are formed.

Thus, we see that digestion in sea-anemones may take place both within the cells and outside the cells. In many other invertebrate animals, also, digestion may proceed simultaneously both in the digestive cavity and inside the cells. However, the higher the organization of an animal, the greater is the importance which digestion outside the cell acquires.

In vertebrate animals, digestion of food takes place completely outside the cells, in the cavity of the intestinal canal, into which juices, containing all the necessary ferments, are secreted by a great number of digestive glands.

Phagocytes. As a result of the development of the animal in the course of many centuries, digestion of food inside the cells lost its original significance; digestion began to take place outside the cells — within the alimentary canal. But digestion inside the cell has not disappeared completely. It remains, but has acquired another no less important significance for the organism.

As the great Russian scientist, Metchnikov, proved, the removal of microbes and of decomposing body cells from the organism is performed by phagocytes by means of digestion within the cell. Phagocytosis, however, does not take the place of the processes of digestion. The phagocytes, like all the other cells of the body, need nutritive materials that are prepared and already digested.

38. The mouth cavity

The structure of a tooth. The mouth cavity is the beginning of the alimentary canal. In the mouth the food is moistened by the saliva and is broken up into small pieces by the teeth. The teeth consist of a compact tissue — *dentine,* which is a kind of bony tissue. The teeth are imbedded in special sockets of the upper and lower jaws. The part of the tooth that is imbedded in the socket of the jaw is called *the root,* while the part that projects outside the socket — *the crown* (Fig. 79). Inside the tooth there is a cavity, filled with a tissue richly supplied with blood vessels and nerves; these enter the tooth through fine canals, which extend to the roots of the tooth. The surface of the crown is covered with a layer of very strong *tooth enamel.* Teeth possess great durability due to their structure.

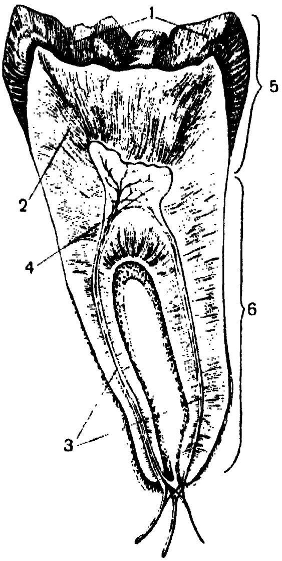

Fig. 79. Structure of a tooth:

1 — enamel of a tooth; *2* — dentine; *3* — canals through which blood vessels and nerves enter the tooth cavity (*4*); *5* — crown; *6* — root.

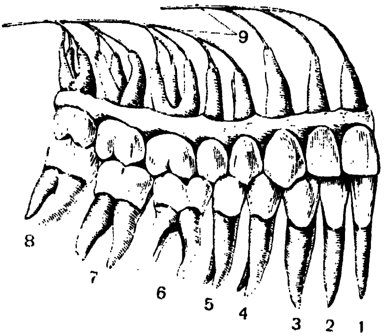

Fig. 80. Teeth of a human being:

1 and *2* — incisors; *3* — a canine; *4* and *5* — premolars; *6*, 7 and *8* — molars (the last one is a wisdom tooth); *9* — branchings of nerves entering the roots of the teeth.

The number and shape of the teeth. A human being has 32 teeth, 16 each in the upper and the lower jaws (Fig. 80). The 4 front teeth of each jaw are called *incisors*; following them, on either side of the jaws, there are one *canine,* two *premolars* and three *molars.*

Chewing and grinding of food is done by the premolars and molars. Tearing off and biting off large pieces is done by the canines. The incisors are used mainly for the biting of food.

The milk teeth. A child first gets temporary, or milk teeth. By the time the child is 2 or $2^{1}/_{2}$ years old, it has twenty teeth: eight incisors, four canines and eight premolars (Fig. 81). The first permanent molars usually begin to erupt at about the age of six to eight. At this age, also, begins the change of teeth: the milk teeth are gradually loosened and fall out as the permanent teeth push their way out to replace them. At about 12 or 14 the change of teeth is over; and, during the same period of time, the second molars begin to grow. The very last molars (one on either side) usually do not appear before the age of 18, and sometimes only at about the age of 25 to 30; these are called the wisdom teeth.

Care of the teeth. In spite of the great hardness of the tooth enamel, small cracks may appear in it. Cracking nuts and biting other hard substances with the teeth, taking extremely hot and cold foods or drinks in close succession (for example, ice-cream after hot tea), will usually crack the enamel. The enamel of children and of adolescents is thinner than that of adults: the teeth of young people are therefore more easily injured. The milk teeth are especially fragile.

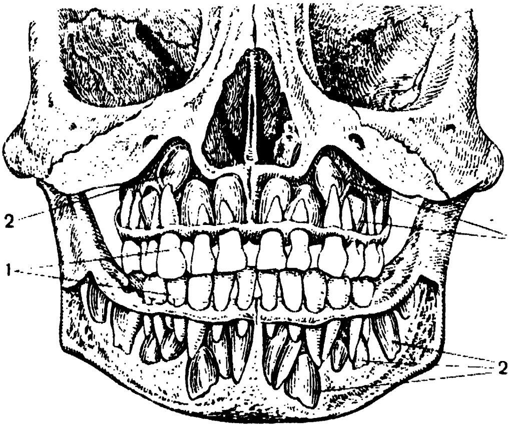

Fig. 81. Milk teeth:

1 — milk teeth; *2* — rudiments of the permanent teeth.

Injury to the enamel usually leads to the gradual decay of a tooth. Decay in one tooth, if not attended to, will always spread to the neighbouring teeth; it is therefore of the utmost importance to have one's teeth examined by a dentist twice a year, with the purpose of stopping or extracting decayed teeth.

Particles of food lodged between the teeth become decayed and spread decay to the teeth. In order to dislodge such particles and thus avoid decay of the teeth, it is necessary to brush the teeth with tooth powder every night before going to bed; the outer surface of the teeth should be brushed first, from the top down and from the bottom up, and then the inner surface. The mouth should be rinsed with drinking water after each meal.

The salivary glands. The mouth cavity is always moist. The moisture is caused by the secretion of mucus from a great number of small glands imbedded in the walls of the mouth cavity, and also by the secretion of saliva from three pairs of large salivary glands: *the parotid*, *the sublingual* and *the submaxillary glands* (Fig. 82). These glands resemble a cluster of grapes in their structure. They consist of a great number of tiny glands, having the shape of little balls or sacs. The ducts of all these little glands unite to form one common duct, opening into the mouth and secreting saliva.

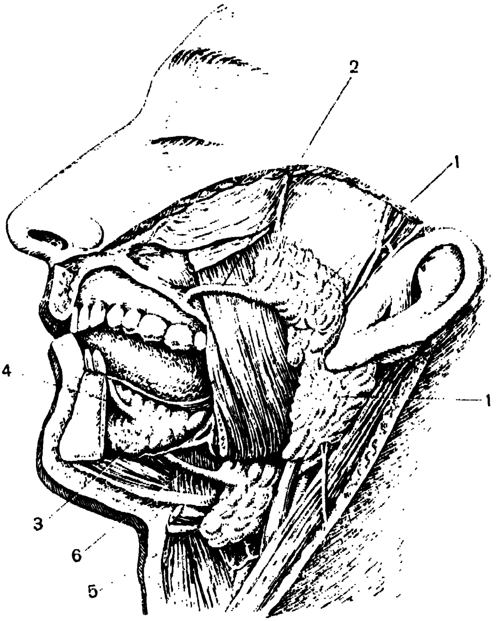

Fig. 82. Salivary glands:

1 — parotid glands; *2* — duct of the parotid gland; *3* — sublingual gland; *4* — duct of the sublingual gland; *5* — submaxillary gland; *6* — duct of the submaxillary gland.

A person secretes from 600 to 700 *cu. cm.* of saliva a day. The saliva moistens dry food and washes away any injurious or foreign substances from the mucous membrane of the mouth.

In the human being, one of the constituents of saliva is the ferment *ptyalin*, which helps to convert *starch* into *maltose*. Another ferment found in the saliva continues the process of decomposition already begun, and converts the maltose into *grape sugar*. Thus, the saliva takes part in the digestion of carbo-hydrates contained in the food.

Swallowing. After the food has been moistened by the saliva and masticated, it is propelled into the pharynx by the movements of the tongue. When the food reaches the pharynx, the soft palate rises, closing the entrance to the nasal part of the pharynx; the larynx is drawn upward and is closed by the epiglottis, which bends back. The epiglottis acts as a protecting shelf to prevent food from getting into the nasal part of the pharynx and into the larynx.

The pressure of the tongue on the bolus of food forces the food into *the oesophagus* — a muscular tube lined with mucous membrane (Fig. 83).

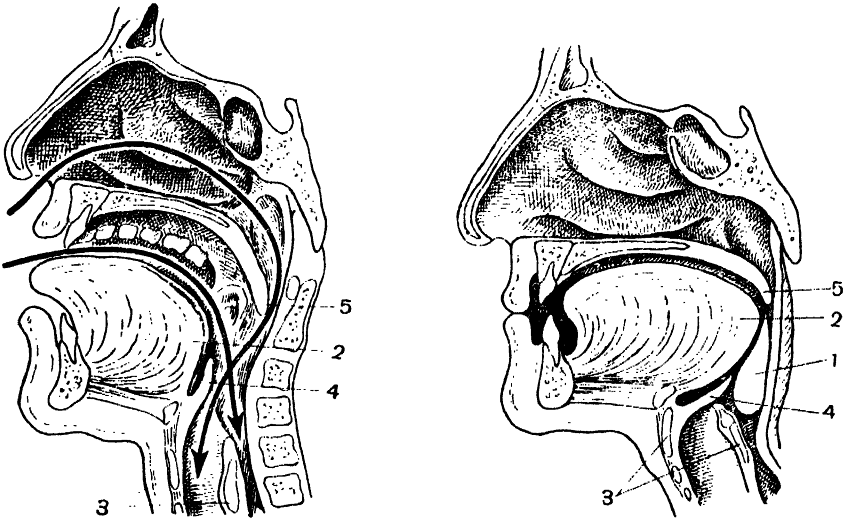

Fig. 83. Act of swallowing. Left — diagram showing the path traversed by air in respiration and by a food ball in swallowing; right — the food ball at the moment it is swallowed:

1 — food ball; 2 — tongue; 3 — larynx; 4 — epiglottis; 5 — soft palate.

The muscles of the upper part of the oesophagus are of a striated structure. The rest of the oesophagus contains smooth muscle fibres, which, in contracting, produce a series of wave-like circular contractions of the whole tube. The wave of contractions first sets the upper part of the oesophagus into motion, then, spreading through the oesophagus, reaches the stomach. Thus, by means of such vermiform contractions, the food is propelled into *the stomach.*

Problem. Make a diagram of the structure of a tooth.

39. The stomach

The structure of the stomach. The stomach is the widest part of the alimentary tube. In the wall of the stomach, as in all other parts of the alimentary tube, there is a thick layer of muscle and an inner layer of mucous membrane. The inlet to the stomach and the outlet from it are usually closed, due to the contractions of the circular muscles situated at the point where the oesophagus merges into the stomach and at the point where the intestines begin. The muscles are relaxed during the passage of a bolus of food.

In the mucous membrane of the stomach there are about five million little glands that have the shape of tiny branching tubes (Fig. 84). These little *glands* secrete daily about two litres of gastric juice, by means of which the food proteins are digested.

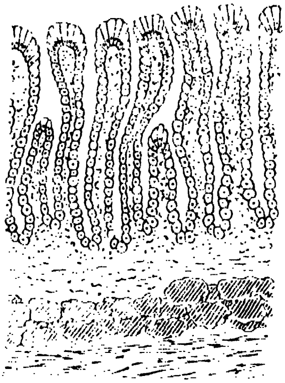

Fig. 84. Gastric glands. Part of the muscular layer of the stomach wall is seen at the bottom.

Gastric juice. Gastric juice contains the ferment *pepsin,* and *hydrochloric acid.* The pepsin acts on *the proteins* of the food and begins the work of digestion. But the ferment cannot carry on its work without an acid medium. Besides this, the acid plays a protective role in destroying most of the microbes that find their way into the stomach with the food.

Lumps of food that have been moistened by saliva and have got into the stomach, usually remain there in an inert state for a great length of time, compressed by the contracting walls of the stomach. Sour juice, secreted by the numerous gastric glands, begins to act gradually upon the food mass and forces its way very slowly into the centre of the food mass. Therefore, the digestion of proteins begins first only at those points where the food comes in contact with the walls of the stomach.

Carbo-hydrates are also digested in the stomach by the ferments of the saliva which get into the stomach together with the food. However, the ferments of the saliva do not act in the presence of hydrochloric acid. Therefore, the splitting up of the carbohydrates is carried on in those parts of the food mass into which the sour gastric juice has not yet penetrated.

The passage of food into the intestine. In the course of digestion, food passes into the lower part of the stomach, which leads to the exterior. In the lower part of the stomach, the wave-like contractions of the stomach wall begin to churn the food mass, which then enters the intestine in small portions.

40. The intestinal canal

The intestines. Food passes from the stomach into the intestines and is carried a long way, at first through *the small intestine* and then through *the large intestine* (Fig. 85). As it moves slowly along, the food is gradually digested. The products of digestion are absorbed from the intestinal canal into the blood.

The intestinal canal of a human being is longer than that of carnivorous animals, but it is considerably shorter than that of herbivorous animals: in a dog it is $4^1/_2$ times longer than its body; in sheep it is 24 times longer, and in human beings it is 9 times longer. The length of the intestinal canal depends upon the character of the food used. Vegetable food contains less nutritive material than meats; furthermore, cellulose, which composes the membrane of plant cells, is very slowly digested. Therefore, vegetable food is consumed in greater quantities and remains in the intestinal canal for a longer time.

The duodenum. The first segment of the small intestine is called the duodenum. The ducts of *the pancreas* and of *the liver* open into the duodenum. Both the pancreas and the liver, like the salivary glands, are closely connected with the alimentary tube, not only because they take part in the digestive process, but also because of their development: both of them first appear in the embryo in the form of lateral growths of the alimentary tube.

The pancreas. The pancreas is the same kind of a complex branching gland as the salivary glands. Pancreatic juice contains ferments which act upon all three of the chief constituents of food: proteins, fats and carbo-hydrates.

The splitting up of *proteins* by means of pancreatic juice goes on much more intensely than in the stomach: the proteins are split up into separate *amino-acids*. In pancreatic juice there is another ferment, which, like the ferment ptyalin, converts *starch* into *sugar*. A fatty ferment splits up *the fats* into *glycerol* and *fatty acids*.

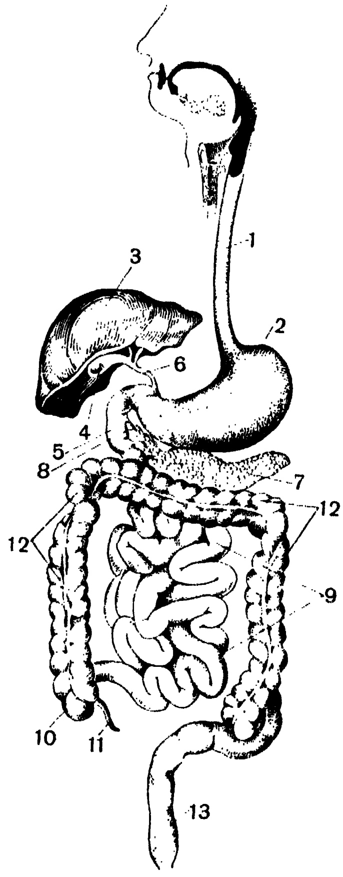

Fig. 85. Diagram of the organs of digestion:

1 — oesophagus; 2 — stomach; *3* — liver; *4* — gall bladder; *5* — duodenum; *6* — bile duct; *7* — pancreas; *8* — pancreatic duct; *9* — small intestine; *10* — caecum; *11* — vermiform appendix; 12 — large intestine; *13* — rectum

The liver. The liver is situated in the upper part of the right side of the abdominal cavity, just below the diaphragm. This is a very large organ; its weight in an adult person is approximately one kilogram.

The liver is supplied with blood, rich in oxygen, by an artery, as all the other organs are supplied. Besides the artery, there is a vein, which opens in the liver, and contains blood coming from the stomach, the intestinal canal, the pancreas and the spleen (see coloured plate II). In the liver, this vein breaks up into many branches and again forms capillaries. As a result, the blood flowing through the intestinal canal passes through the capillaries *twice.* This specific feature is connected with the great role that the liver plays in metabolism and, in particular, with its role in the further processes that the digested and absorbed nutritive materials must pass through.

One of the functions of the liver is to produce *bile*, which passes into the duodenum through the bile duct. Although the bile itself contains no digestive ferments, it facilitates the action of other ferments, and thus facilitates the digestion of the nutritive materials. The production of bile in the liver goes on continually; but bile enters the intestinal canal only at the same time the food pap, or chyme, from the stomach enters the duodenum. At all other times, bile passes into *the gall bladder,* where it is stored until needed.

The small intestine. The small intestine is the longest part of the digestive tract. Imbedded in the mucous membrane of the small intestine are vast numbers of small *intestinal glands,* which secrete about two litres of digestive juice daily. This digestive juice contains ferments which act on *the proteins, fats* and *carbohydrates,* thus completing their digestion.

Peristalsis in the intestine. If the abdominal cavity of a chloroformed animal is cut open, the slow vermiform movements of the small intestine, coiled in loops, may be observed. These movements are produced by the slow periodic contractions and relaxations of the smooth muscles, situated in the walls of the intestine. Each contraction is communicated, not to all of the intestine at once, but only to a small part of it at a time; thus, the wave of contraction moves gradually along the whole length of the intestine. Such wave-like or vermiform movements of the intestinal wall, usually following one another in succession, is known as *peristalsis*, or peristaltic movements. Peristalsis may also be observed if a piece of intestine, cut out of the body, is immersed in a physiological solution.

Due to peristalsis, the chyme is kept churning and mixing and is moved slowly onward through the intestine.

The intestinal villi. The passage of substances from the external environment through the skin, or through the mucous membrane of the digestive tract, into the blood and lymph is called *absorption.* The absorption of the products of digestion goes on chiefly in the small intestine.

If we put into water a piece of mucous membrane from the small intestine and examine it with a magnifying glass, we may see a great number of folds, thickly covered with fine, finger-like projections that resemble the pile on velvet. These little projections are called villi (Fig. 86). Due to the folds, and especially to the villi, the surface of the intestine is considerably increased, thus accelerating the absorption of nutritive material.

Inside each villus there is a network of minute blood vessels; within each villus, also, a lymph vessel has its origin and extends through the length of the villus; all the little lymph vessels of the villi open into the lymph vessels of the intestinal wall.

Absorption — a physiological process. Formerly it was supposed that absorption was simply the infiltration of the products of digestion through the walls of the villi. However, a detailed study of the process of absorption showed that by far not all substances pass through the walls of the villi. Notwithstanding the magnitude of the pressure of the liquid and of the concentration of substances on both sides of the walls of the villi, substances can pass only in one direction — from the intestines into the villi. This means that absorption is a physiological process which cannot be explained by the laws of filtration and osmosis. Absorption is the result of the active work of the cells, which form the surface layer of the villi.

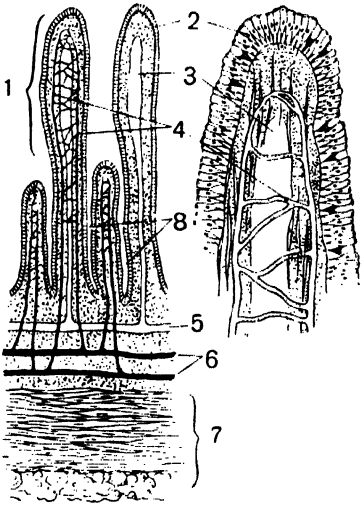

Fig. 86. Diagram of the structure of a villus; (right — part of a villus highly magnified):

1 — villus: *2* — layer of cells through which absorption takes place; *3* — origin of the lymph vessel in the villus; *4* — blood vessels of the villus: *5* — lymph vessel in the intestinal wall; *6* — blood vessels in the intestinal wall; *7* - part of the muscular layer of the intestinal wall; *8* — intestinal glands.

The role of the liver as a barrier. The products of digestion that have been absorbed into the blood get into the liver first of all, since the blood from the intestinal canal first flows into the liver, and after that to the heart. The passage of the blood in such a way is of very great importance.

When eating food cooked in copper pots that are not tinned, invisible particles of copper find their way into the digestive tract, where they are converted into soluble salts by the action of the acids in the gastric juice, and in the form of soluble salts may get into the blood. Other substances, such as compounds of lead, zinc, arsenic and many other substances injurious to the health, which are to be found in the dust of some factories, may also get into the blood. Such substances are always to be found in great quantities in our environment.

The liver either renders harmless such poisonous substances, brought by the blood from the intestinal canal, or converts them into an insoluble state, and then eliminates them with the bile. When they enter the intestinal canal again, they are already in an insoluble state and are eliminated from the intestinal canal together with the faeces. In this way the liver serves as one of the barriers between the exterior and the interior mediums of the organism.

The large intestine. Chyme that has not been absorbed into the small intestine enters the large intestine; here the process of absorption is completed; however, it is water that is mainly absorbed here.

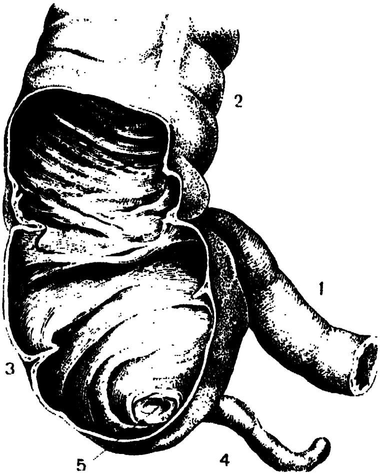

Fig. 87. Caecum:

1 - small intestine; 2 — large intestine: 3 — caecum; 4 — appendix; 5 — opening of the appendix.

The last segment of the large intestine, through which waste material is eliminated to the exterior, is called *the rectum.*

The caecum. The first segment of the large intestine is called the caecum (Fig. 87).

In some herbivorous animals, the caecum is of a tremendous size; the caecum of the horse has a cubic content of about 30 litres. Its great size is due to the fact that the splitting up of the plant cellulose goes on within it by means of fermentation produced by microbes.

The caecum of the human being, in comparison with that of animals, especially herbivorous animals, is not large.

The vermiform appendix. Extending from the caecum is a thin vermiform projection known as the appendix (Fig. 87).

In a middle-aged person, the opening of this vermiform appendix is often completely fused together. The appendix, evidently, is of no importance to the vital activity of the human organism. Nevertheless, it often proves to be very harmful to a person. Food collects and decays there, or intestinal worms settle there and may cause inflammation of the appendix, or appendicitis. In such cases, an operation is often performed, in which the appendix is completely removed.

41. I. P. Pavlov and his work on the physiology of digestion

The role of Pavlov in the development of the physiology of digestion. The study of the digestive process is almost wholly connected with the development of our own native science. It is an established fact that Russian scientists, and foremost among them

I. P. Pavlov, created a real revolution in the study of digestion, which, not without cause, is called abroad "the Russian branch of physiology."

The biography of I. P. Pavlov. Ivan Petrovich Pavlov was born in 1849, in the family of a priest. Ivan Petrovich graduated from a theological seminary; but, influenced by the advanced ideas of his time, he decided to study the natural sciences. For this purpose, he entered the natural science faculty of the University of St. Petersburg. When in the second year at the university, he was already conducting scientific investigations. His first scientific work, while still a student, was devoted to the study of the innervation of the pancreas, for which he was awarded a gold medal.

After finishing the university, Pavlov entered the Medico-Surgical Academy and graduated from it in 1879.

The leading physicians of the time understood that in order to treat and cure patients successfully, one must have a deep scientific know ledge of physiology. S. P. Botkin, a famous physician and professor at the Medico-Surgical Academy, decided to organize a special laboratory for the study of physiology and of digestion in animals. The young and modest scientist, I. P. Pavlov, was invited by Botkin to work in his laboratory; by this time, however, Pavlov had already succeeded in making himself known as a persistent and fervent investigator.

Pavlov began his research work with enthusiasm. The entire laboratory consisted of one room. But this did not prevent him from doing creative work on a wide scale. It was here that he performed his remarkable work on the innervation of the heart. Here also he began those brilliant experiments which resulted in the discovery of a new approach to the study of the work of the digestive organs.

After some years had passed, Pavlov went abroad and met the greatest physiologists of that time, but it turned out that there was nothing he could learn from these foreigners, that there was much he could teach them. And, indeed, it was not long before foreign scientists began to arrive in Russia, in order to learn new methods of work from Pavlov.

There was never a time that Pavlov was without pupils. To his little laboratory came physicians interested in physiology, and for each of them there was work. A friendly cooperative atmosphere reigned in his laboratory. Pavlov infected those around him with his own enthusiasm for work, with his own great devotion to science. As a result, many of his pupils became famous physiologists or physicians.

In 1891 the Institute of Experimental Medicine was founded. Beginning with 1891, Pavlov was the head of the physiological department of this institute, and remained its head to the end of his life. Here he continued his study of the physiology of the digestive tract, investigating the specific features of the work of each gland. By means of different and often very complex and ingenious experiments, Pavlov made a detailed study of the regulation of the work of the digestive organs and of their adaptation to the changing needs of the organism and to the various constituents of food.

A few years later, Pavlov received the title of professor and was elected head of the chair of physiology at the Medico-Surgical Academy. In 1906 he was elected a member of the Academy of Science.

Pavlov's name became widely known abroad, and in 1904 he was awarded an international prize for his outstanding work on the physiology of the digestive tract.

However, by that time Pavlov was already less interested in problems of digestion. By making a study of the work of the salivary glands in dogs, he determined that the activity of the salivary glands was aroused, not only when food was in the mouth of the dog, but by agents acting at a distance, such as the sight and the odour of food. Furthermore, the secretion of saliva was stimulated in the dog by the sound of the footsteps or the voice of the person who was in the habit of bringing it food.

Taking these facts into consideration, Pavlov made an attempt to utilize them in the study of the higher division of the brain — the cortex of the cerebral hemispheres. This attempt was crowned with complete success. Pavlov spent more than 35 years in studying higher nervous activity, and used his work with the salivary glands as an indication of this activity. Thus, as a result of the work of Pavlov and his numerous co-workers, a completely new branch of physiology was created – the science of conditioned reflexes.

The tzarist government showed little interest in the great scientist. Pavlov's limited means did not give him the possibility to conduct his work on a wide scale. During the imperialist war, Pavlov's laboratory came almost to a complete standstill.

It was only after the Great October Revolution that favourable conditions were created for the scientific activity of Pavlov and his co-workers. During the Civil War, the Soviet government took special measures to improve the living and working conditions of Pavlov, — and our government did this in spite of the extremely hard conditions of life of the period. By a decree of Lenin, the dogs which Pavlov used in his laboratory were regularly and continuously supplied with food. Thus were saved the animals on which Pavlov, in his study of conditioned reflexes, had for so many years experimented.

Pavlov understood and appreciated the importance of the great building up of a new life in our country. He set to work with still greater energy on his beloved science, striving, by means of his scientific work, to be of maximum use to his own people and to all humanity.

"No matter what I do," Pavlov once said, "I always keep in mind that I am serving, so far as it is in my power to do so, first of all, my native land."

In 1935 an international conference of physiologists took place in the U.S.S.R., and to it came the greatest scientists from all the countries of the world. This conference unanimously voted Pavlov "the world's greatest physiologist."

Pavlov died in 1936.

A short time before his death, when the 10th Congress of the Leninist Young Communist League took place, the great Soviet scientist, ardent patriot of his native land, wrote an open letter to the Soviet Youth; in this letter are reflected Pavlov's chief traits, characteristic of him both as a scientist and as a man. The full text of this remarkable document is given in the preface to this textbook.

The new method of studying digestion. In 1842 a Russian scientist, Basov, had already performed an operation on a dog, as a result of which it was possible to investigate the contents of the stomach at any time. The operation was as follows: the abdominal cavity of an animal was cut open; an opening was made in the wall of the stomach, and in this opening was inserted a small metal tube, so that one end of it was in the abdominal cavity, while the other end was conducted outside the body. The outside end was stopped with a plug; the wound around the tube was sewn up. The dog did not suffer from this operation.

Thus, as a result of the operation, an opening, or *fistula*, was made, through which it was possible to investigate the interior of the stomach at any time.

Other scientists also tried to make such a fistula in various parts of the digestive tract. But it was only Pavlov, and his numerous associates, who succeeded in improving and perfecting the method of making fistulae to such an extent that it was possible to carry on a deep and detailed study of the work of the digestive organs. The problem did not consist only in learning to make a fistula in any part of the digestive tract; it was a greater problem to obtain, by means of the fistula, digestive juice, unmixed with food and with other juices, and, what was particularly important, to see that the fistula did not injure or interfere with the normal work of the intestinal canal.

After many persistent attempts, Pavlov succeeded in making a chronic (constant) fistula connected with the pancreas. Pancreatic juice empties into the duodenum through two ducts. One of these ducts Pavlov conducted to the exterior of the dog's body and sewed it to the skin together with a small piece of intestine. Now the juice was eliminated through one duct, as before, into the intestine, while through the other duct it was eliminated outside the body. But it was observed that the animals operated on suffered very much from ulcers, which developed around the fistula, so that most of them soon died. However, Pavlov's extraordinary powers of observation helped him to overcome this difficulty.

One day Pavlov noticed that one of the dogs, soon after the operation, began to gnaw at plaster, and then, collecting it in a small heap, lay down on this porous lime bed; as a result, no ulcers formed around the fistula of this dog. This incident, which taught Pavlov the method of struggle with the erosive action of pancreatic juice, the great scientist remembered all his life. In 1935, when, at the initiative of Pavlov, a monument to a dog was put up in the courtyard of the Institute of Experimental Medicine in Leningrad, the following inscription was engraved on the monument: "By crushing plaster into small pieces and making a porous bed out of it, the dog suggested to the experimenter the method to be used in preventing erosion of the stomach by the pancreatic juice, when it flowed out of the artificial opening."

By applying various kinds of fistulae, sometimes several of them on one dog, Pavlov studied the work of the whole digestive tract, thus making clear the interconnection and interaction between its different parts.

Pavlov's work in the field of digestion created a real revolution in physiology by demonstrating graphically the importance of studying the work of an organ in the natural conditions of the whole organism.

The work of Pavlov and his co-workers is of the greatest importance in understanding the processes that go on in the human organism: their work determines the most important rules of the hygiene of nutrition, helps to differentiate and diagnose the various diseases of the digestive organs and to choose the correct method of treatment.

42. The regulation of the work of the digestive glands

The regulation of salivary secretion. To study the work of the salivary glands in animals, Pavlov made artificial fistulae and conducted the glandular duct to the exterior of the body (Fig. 88). In order to study salivary secretion in the human being, special suckers are used, which are attached in the mouth cavity so as to be directly opposite the outlet of the duct of the salivary gland (Fig. 89).

In a human being and in animals, the main salivary glands secrete saliva reflexly. Food that is in the mouth cavity stimulates the endings of the gustatory nerves. The impulses aroused in them are transmitted to the medulla oblongata, and from there, along other (efferent) nerves, reach the glands and bring them into action (Fig. 90).

The sight and the smell of food, and even a conversation about food, stimulate the corresponding nerve endings (optic, olfactory or auditory), and call forth the secretion of saliva, the result of a conditioned reflex; the saliva secretion is brought about with the participation of the cortex of the cerebral hemispheres. The mere thought of tasty food is enough "to make the mouth water." The nature of salivary secretion at the sight of food, or when talking about food, is exactly the same as that which occurs when the same food is introduced into the mouth.

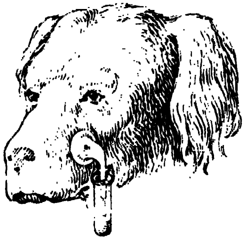

Fig. 88. Dog with a salivary fistula.

The regulation of the work of the gastric glands. When food is taken into the mouth, as well as at the sight or smell of food, the secretion of gastric juice begins at the same time that the secretion of saliva begins.

Pavlov performed a double operation on a dog and proved that the secretion of gastric juice takes place reflexly. The operation performed was as follows: first, a fistula was made in the stomach of the dog; then the oesophagus was cut across and the two ends thus produced were sewn to the skin of the neck. After the operation, any food that was swallowed could not get into the stomach (Fig. 91). To prevent the dog from dying of hunger, food was conducted directly into the stomach through the fistula.

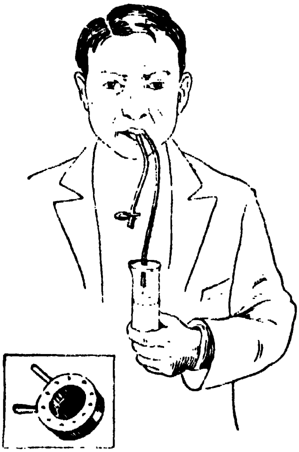

Fig. 89. Investigation of salivary secretion in a human being; at the bottom — sucker used to collect the saliva.

The experiment demonstrated that a few minutes after the "*sham feeding*," when the food fell out of the stomach through the opening of the cut oesophagus, the empty stomach began to secrete pure gastric juice. The secretion continued for about one or two hours. When the little branches of the vagus nerve, which leads to the stomach, were cut, the "sham feeding" did not arouse any secretion of juice. This proves that the work of the gastric glands is regulated by the nervous system, that is, it is regulated *reflexly*. Thus, the reflex secretion of gastric juice may be *unconditioned*, as well as *conditioned*; that is, it takes place with the participation of *the cortex of the cerebral hemispheres*.

In order to collect and examine gastric juice in the pure state, without any admixture of food in it, Pavlov performed a very complex operation: he cut the stomach into two unequal parts, —

into a large stomach, and *a small,* or *isolated stomach.* The food in the oesophagus could enter only the large stomach, and from the large stomach it could pass into the intestinal canal. The small, or isolated, stomach was a closed-up bag (pouch), with an opening leading to the exterior of the body. The operation was a very complex one, because special care had to be taken not to injure in any way either the blood vessels or the nerves leading to the isolated stomach. Under these conditions, the isolated stomach, in which there was no food, kept on secreting juice exactly as the large stomach.

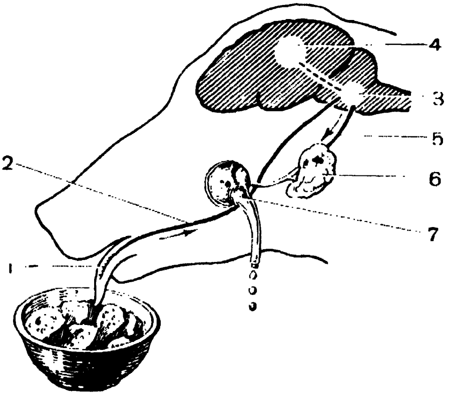

Fig. 90. Diagram of a salivary reflex:

1 — receptive nerve endings in the tongue; 2 — an afferent nerve; 3 — salivary centre in the medulla oblongata; 4 — a zone of excitation in the cerebral cortex; 5 — an efferent nerve; 6 — a salivary gland; 7 — a funnel.

Observations showed that when food entered the stomach after a normal meal, the juice continued to flow for a period of four to six hours, and even for eight hours running — and not for one or two hours, as was the case in "sham feeding."

The flow of gastric juice, in such a case, is prolonged by means of humoral regulation. During digestion, certain substances are absorbed into the blood through the wall of the stomach. These substances in the blood cause excitation of the gastric glands, and, as a result, the flow of juice continues.

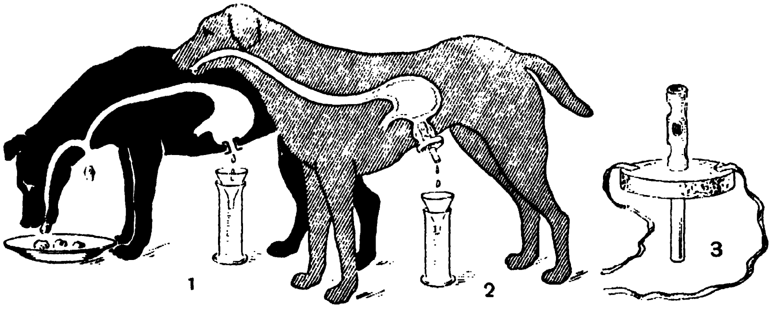

Fig. 91. Diagrammatic representation of some types of operations applied in studying digestion in the stomach:

1 — shows the application of a fistula in the stomach, and the cut oesophagus; 2 — the small isolated stomach; 3 — tube used for collecting the juice from the isolated stomach.

A Soviet scientist, I. P. Razenkov, demonstrated, by an experiment, that if certain substances (meat juices, or the products of the digestion of proteins) are introduced into the blood of a dog or under its skin, gastric juice will begin to flow, even if the animal does not receive any food.

It is possible to avoid the reflex secretion of juice by taking a dog with an isolated stomach and with a fistula applied to the large stomach, and introducing some food directly into its stomach, but so that the dog is not aware of it. In response to the introduction of food in such a way, gastric juice begins to flow, not immediately, but in 15 to 30 minutes; in the case of some foods, it does not flow at all. Thus, bread, after lying in the dog's stomach for several hours, remains undigested because of the absence of gastric juice.

But if a piece of bread is shown to the dog, or if it is allowed to smell it, after some bread has been introduced into its stomach through a fistula, then a copious reflex flow of juice immediately begins; also, after some time, the substances that have been absorbed into the blood bring about prolonged humoral excitation of the gastric glands.

It is clear from these experiments that the humoral secretion of juice depends, to a great extent, on the initial secretion brought about by reflex action. Consequently, the participation of both *humoral* and *reflex* regulation are equally necessary for the normal digestion of food.

In order to study the work of the gastric gland of a human being, the contents of the stomach is usually drawn out with the help of a rubber tube introduced into the stomach through the mouth. In several cases it was even possible to observe and study patients, in whose stomachs fistulae had developed as the result of a wound or some other injury.

The regulation of digestion in the intestines. The entrance of pancreatic juice and bile into the duodenum is also subjected to both reflex and humoral regulation. *Reflex regulation* may take place without the participation of the cortex of the cerebral hemispheres (unconditioned reflexes) as well as with its participation (conditioned reflexes); therefore, the mere sight or smell of food is enough to cause the secretion of juices. However, the flow of juice caused by reflex action is slight in comparison with that produced by the action of the *humoral* stimuli.

Pavlov determined that an abundant flow of pancreatic juice is brought about when chyme, saturated with sour gastric juice, passes from the stomach into the duodenum. The same may be observed when pure gastric juice or hydrochloric acid is introduced artificially into the duodenum.

When the acid comes in contact with the mucous membrane of the intestine, a special substance — *secretin,* is formed in the intestinal wall. Passing into the blood, secretin spreads throughout the whole body, finds its way into the pancreas and stimulates it, thus intensifying the secretion of juice.

Academician K. M. Bykov succeeded in making a study of the regulation of the work of the pancreas in a human being; he performed some experiments on a patient, in the duct of whose pancreas a fistula had formed as the result of some serious injury.

While eating, or at the sight of food, there is no flow of intestinal juice — that is, no juice is secreted from the glands situated in the walls of the small intestine. Intestinal juice is secreted only in those parts of the intestine that are in contact, at a given moment, with chyme, which irritates the mucous membrane and calls forth local secretion of juice.

Coordination in the work of the digestive organs. The work of all the organs of the digestive tract, beginning with the organs of the mouth cavity and ending with the large intestine, is highly coordinated.

The mere sight or smell of food is sufficient to start a flow of saliva, or gastric and even pancreatic juice. When food is taken into the mouth, the secretion of juice is considerably increased. The composition and quantity of the juices secreted by the digestive glands depend upon the properties and the constituents of the food swallowed.

If a weak solution of hydrochloric acid is introduced into the mouth, there is rather a copious secretion of saliva, but the saliva is very watery, and is more alkaline in its reaction than ordinarily. There is also a copious and watery flow of saliva when dry toast is being eaten. When soft bread is eaten, the saliva is thick, and its quantity is very small. The saliva is still thicker in the case of boiled potatoes, or the hard-boiled yolk of an egg.

The digestive action of the saliva is also not always the same. The saliva of a human being is very rich in ferments (ptyalin) when potatoes are being eaten; when some other foods are eaten (fruit, sweets), the saliva contains few ferments.

Lean meat, in comparison with fat meat, calls forth two or three times greater a flow of pancreatic juice, rich in a ferment that splits up the proteins. In the case of very fatty foods, the amount of ferment which splits up the fats is increased in the pancreatic juice, while the content of other ferments in the juice is decreased.

The composition and quantity of other digestive juices also depend, to a great extent, upon the nature of the food to be digested.

Because of the nervous and humoral regulation of the activity of the digestive glands, the secretion of digestive juices continues in each part of the intestinal canal as long as there is any food in it.

Experiments with animals, and also observations made of people, have proved that when the diet is changed, the work of the whole digestive tract also changes. Thus, a transition from a meat diet to a diet consisting mainly of carbo-hydrates (bread, vegetables, gruel), considerably reduces the amount of gastric juice secreted; the work of the other glands changes also.

However, it must not be thought that the work of the intestinal tract is always adequate to its needs. In many cases the quantity and composition of the digestive juices do not correspond to the nature of the food being digested. Thus, when milk or the yolk of an egg is being digested, saliva, containing a large amount of ptyalin, is secreted. But these foods do not contain starch, and therefore the ferment produced by the gland becomes absolutely superfluous in this case. Many instances may be given of the inadequacy of the work of the glands.

When the idealists speak about "adequateness," they have in mind the idea that each organ exists and every phenomenon takes place "for some purpose" and has "some definite pre-ordained aim." Such a notion has its source in the religious belief that the world was created by a god. Actually, there are organs and functions of the body that are clearly "inadequate." Among these may be mentioned the inactive ear muscles of a human being, the vermiform appendix, and other peculiarities in the structure of a human being, many of which have come down to us from ancestors long dead. Adequateness in the work of the organism is the result of the ability of the organism to adapt itself to the conditions of life in the course of many generations.

The conditions of normal digestion. Normal digestion of food depends, in great measure, upon the initial reflex secretion of the majority of the digestive juices.

The ingredients that make up food, the taste of food, the methods of preparing it, and all the surrounding conditions, influence the work of the glands, and consequently affect the appetite. A dirty table, eating while standing, gulping down one's food in a hurry, and also reading at meals — all this diminishes the reflex flow of juices, thus reducing the appetite.

A person's mood is also of great importance in the work of the digestive tract. Worry, grief, anger, great excitement may bring to a complete standstill the secretion of juices already begun, and thus result in loss of appetite.

The connection of the work of the organs of digestion with the various external conditions and with the state of the organism is established by *the cortex of the cerebral hemispheres.*

Problem. Compose a table of the digestive ferments, showing where each ferment is produced, and how it takes part in the process of digestion.

REVIEW QUESTIONS

1. Of what importance is nutrition to the organism?
2. What nutritive materials enter into the composition of foods?
3. Name the chief groups of foods, give the characteristic features of each group, and show, approximately, the content in each of proteins, fats and carbo-hydrates.

4. Explain the process of digestion. Of what importance is the process of digestion to the organism?

5. Enumerate the parts of the digestive tract in succession and the glands connected with each part.

6. What changes do proteins, fats and carbo-hydrates undergo in the digestive tract?

7. What are the chief rules for the care of the teeth?

8. Why is the study of digestion called "the Russian branch of physiology?"

9. How is a study of the work of the salivary glands made?

10. How is the secretion of gastric juice regulated?

11. What operations did Academician I. P. Pavlov perform that enabled him to make a complete study of the work of the stomach?

12. What are the chief functions of the liver?

13. From what organs does the blood enter the liver through the portal vein? Of what importance is this?

14. What is absorption? Where and how does it go on?

VI. METABOLISM AND THE TRANSFORMATION OF ENERGY

43. Metabolism and the transformation of energy — the main life functions

Metabolism (the interchange of substances) as a necessary condition of life. Metabolism is not only the introduction into the organism of nutritive materials and oxygen from the surrounding medium, and the elimination from the organism of waste products; metabolism is the sum total of all the complex and various changes that take place in the organism. Metabolism lies at the basis of all the vital manifestations, and goes on continuously in each organism; in other words, metabolism is the necessary condition for the existence of the organism. With the cessation of metabolism, all life functions cease, and the organism dies.

A change in matter is always accompanied by a transformation in energy. Thus, for example, when complex organic substances decompose, the potential, that is, the latent chemical energy contained in them, is released and is converted into heat energy or into mechanical energy. It is impossible to separate metabolism (the interchange of substances) from the transformation of energy: the two processes are inseparably connected with each other.

Metabolism goes on not only in the living organism, but in all nature that surrounds us. "But the difference lies in this," says Engels, "that in the case of inorganic bodies, metabolism decomposes them; while in the case of organic bodies, metabolism is the necessary condition for their existence."

Assimilation and disassimilation. Substances that get into a cell of the body are not simply collected and stored there. They undergo complex changes and are converted into the very material of the cell itself. This ability of a cell to assimilate substances and to utilize them for its own building up is called assimilation. In the process of assimilation, that is, in the process of the formation of living substance, the cells not only enrich and renew themselves, but they also acquire the latent (potential) energy contained in the new substance.

Alongside with the process of the building up of living substance, a partial breaking down process is also constantly going on. The destruction, or the decomposition, of the substances that enter into the composition of the living cell is called disassimilation. In the process of disassimilation, potential, or latent (chemical) energy is released, which is converted into another form of energy — chiefly mechanical and heat energy. As an example of this, we may take the phenomena which occur in a skeletal muscle. When irritated, chemical changes take place in the muscle tissue. During these chemical changes, the potential energy of the muscle is converted into mechanical energy (the muscle contracts and lifts a load) and heat energy (the temperature of the muscle rises).

As a result of assimilation, matter and energy are accumulated in the organism. Disassimilation, on the contrary, means a reduction, an expenditure, of matter and of energy. Both of these processes go on incessantly and in close connection with each other. They are as inseparable from each other as the processes of the changes in matter and the transformation in energy. The assimilation of one kind of matter is always accompanied by the disassimilation of another kind of matter. Any increase in one of these processes is followed by an intensification of the other. When the organism is in the process of growth and the amount of living matter in it keeps on increasing, the processes of decomposition are intensified in proportion as assimilation is intensified.

Assimilation and disassimilation are so closely intertwined, and are so dependent upon each other that they may truly be considered two phases of one and the same process — the process of metabolism and the transformation of energy in the organism.

The law of the conservation of matter and of energy. In the living organism, as in all nature, matter and energy cannot be created out of nothing, neither can they be destroyed. They are merely subjected to an infinite number of changes. The source of matter and of energy in the organism can be only food and the energy contained in food.

The amount of nutritive material that enters the organism and the amount of potential energy contained in that material may be calculated with great exactness. The amount of material and of energy expended by the organism may be determined with the same exactness.

Numerous experiments performed with animals, as well as with human beings, have proved that if the weight of the body remains unchanged, the expenditure of matter and of energy is exactly equivalent to the income of matter and of energy, that is, to their introduction into the body with food.

Thus, we may draw the conclusion that the law of the conservation and transformation of matter and of energy can be applied in equal measure both to the inorganic and to the organic world.

The complexity of the phenomenon of metabolism. The introduction of material into the organism and its elimination to the exterior — are merely the first and the last stages in metabolism. The materials that enter the organism undergo a number of protracted and complicated changes, connected with the processes both of assimilation and of disassimilation. And it is just these changes that constitute the essence of the process of metabolism.

Metabolism in the various organs differs. This may be explained by the difference in the chemical composition of the protoplasm of their cells. There is great variety, especially in the proteins of the various organs. In the process of assimilation entirely different kinds of proteins are formed out of the amino-acids; but each kind of protein is always specific for a given cell, for a given organ.

Although the end products of decomposition are the same in all the organs (carbonic acid, water, ammonia, etc.), the intermediary products of disassimilation in the different organs are by far not the same.

Certain products of metabolism, which find their way from the blood into other organs, may influence the work of these organs. An example of this is the improved appetite and the general increase in vital activity which usually follow physical work. This is due to the fact that certain intermediary products of metabolism, formed in the muscles during their activity, enter the blood. If too much and too strenuous physical work is performed, there is too great an accumulation in the blood of the products of metabolism in the muscles, and the result is a reaction in the opposite direction: the excitability of the organs, in particular that of the digestive glands, is noticeably diminished, and a loss of appetite follows.

The role of ferments, or enzymes, in metabolism. A great number of ferments, each of which accelerates a definitely specific chemical reaction, participate in the complex and varied processes of metabolism that go on in the organism. The ferments are produced as a result of the activity of the living cells; in other words, they are the products of metabolism. At the same time, the participation of ferments in all the processes of metabolism is absolutely necessary; without ferments life in the organism becomes impossible.

Many scientists, among them the Soviet academicians A. N. Bach and A. I. Oparin, have done much work in studying the role of ferments in oxidation, as well as in various other processes that go on in the organism. It has been determined that any interference in the activity of the ferments may cause very serious disorders in the processes of metabolism, and may even cause the death of the organism.

44. The metabolism of proteins, fats, carbo-hydrates and salts

The metabolism of fats. Fats are absorbed almost exclusively in the form of the products of their separation — glycerol and fatty-acids. However, the molecules of fat are restored again in the cells of the intestinal villi.

There are many different kinds of fats in food. Thus, mutton fat differs from beef fat or pork fat; there are various kinds of vegetable fats also. But the fat which is formed in the walls of the villi from the products of digestion always possesses properties which are peculiar only to the fat of a human being.

The absorbed fat enters the lymph, and from there it is carried by the lymph vessels to the blood-vascular system. It is distributed, together with the blood, to all the organs and tissues. The excess fat is stored in the cells of the fatty tissue; for instance, in the subcutaneous fatty tissue.

The metabolism of carbo-hydrates. Carbo-hydrates are absorbed into the blood in the form of simple sugars, chiefly *grape sugar*, or *glucose*. Excess sugar is retained in the liver and also in the muscles, where it is converted into *animal starch,* or *glycogen.* The amount of carbo-hydrates stored in the organism does not exceed 500 or 600 grams. In proportion as it is needed, a part of the glycogen is again converted into sugar, which again enters the blood and is used up as nutrition by the organs and the tissues of the body.

Carbo-hydrates are one of the chief sources of energy of muscle contraction. Carbo-hydrates are also necessary for the activity of the nervous system.

The pancreas takes part in the metabolism of carbo-hydrates. The pancreas produces a substance — *insulin* — which helps to turn the sugar into animal starch. Insulin does not enter the excretory duct of the pancreas, but passes directly into the blood. If the pancreas does not secrete the necessary amount of insulin, the liver and the muscles lose their ability to hold the sugar; thus, the content of the sugar in the blood is increased. In such a case, the kidneys begin to eliminate the excess sugar with the urine.

As the result of any disorder in the activity of the pancreas, all the sugar in food, not retained by the liver, is eliminated with the urine. This happens in the case of diabetes, which is often the cause of death. Patients suffering from diabetes are treated by injecting insulin in the blood.

The conversion of glycogen back again into sugar is intensified by the action of a substance already known to us — *adrenaline*.

The metabolism of proteins. The end products of the digested proteins of food are *amino-acids,* which are absorbed, unchanged, through the walls of the intestinal canal, and pass into the blood. Each living tissue uses up a part of its proteins. Amino-acids, absorbed from the blood, is the material out of which exactly the same kinds of proteins are formed again.

Proteins do not accumulate and are not stored in the organism. If there is an excess supply of amino-acids from the intestinal canal, they are partly converted into carbo-hydrates. Nitrogen, which is one of the constituents of amino-acids, but is not contained in carbo-hydrates, is eliminated in the form of ammonia, and is not utilized by the organism. The conversion of carbo-hydrates back again into proteins does not take place in the organism of the human being or of animals.

The role of the liver in metabolism. The activity of the liver is responsible, to a great extent, for the conformity between the amount of proteins, fats and carbo-hydrates absorbed, on the one hand, and the needs of the organism, on the other hand; that is why the liver is sometimes called the central laboratory of our body.

It is in the liver that amino-acids are converted into carbo-hydrates, if a person's diet consists chiefly of protein foods. In the liver, also, carbo-hydrates can be turned into fat, and fat into carbo-hydrates. That is why fat accumulates in the organism even when the food is rich in carbo-hydrates (starch, sugar) and contains little fat.

During the process of metabolism, a certain amount of substances which are injurious to the organism is always formed. Many of these substances undergo changes in the liver and are rendered harmless. Thus, for example, poisonous *ammonia* is converted, in the liver, into harmless *urea*, which passes into the blood and is later eliminated with the urine.

Metabolism in cases of over-indulgence in food. When an ordinary, normal amount of food is taken into the body, the weight of the body remains unchanged; in other words, the amount of material that enters the organism is equal to the amount that is eliminated from it.

With an increased amount of food, a part of the excess nutritive material absorbed is very quickly destroyed and is excreted from the organism, while a part remains and is stored in the form of fat. In such a case the body gains weight.

Obesity, which is often the result of over-eating, is harmful. Obesity weakens the activity of the organism, interferes with the work of the heart and of other important organs, destroys correct and regular metabolism, and is sometimes the cause of serious illnesses.

Metabolism in cases of starvation. With an insufficient supply of food, a person may lose more material than he obtains from the surrounding medium. The loss of weight which follows insufficient nutrition shows that the organism is living at the expense of its own stores. If a person loses from 30% to 40% of his original weight, death from hunger results.

A certain scientist made an experiment with two cats of the same weight, age and sex. Both cats received the same amount of food for a certain length of time. Then one of them was killed, while the other was deprived of all food; after thirteen days it died of hunger. On weighing the different organs, it was found that several organs and tissues of the starved cat weighed much less than those of the cat that had not been starved; the weight of the muscles was about one-third of that of the other cat's, while the liver weighed half as much; the fatty tissue had almost entirely disappeared. Those organs that are most important for life, especially the central nervous system and the heart, remained practically unaltered in weight.

This experiment shows that in cases of starvation which continues for a long time, the organism feeds, so to say, upon itself: in order to maintain the activity of the most important organs — the heart and the nervous system — the organism lives upon those substances which enter into the composition of the cells of other organs that are less important for life (for example, the muscles).

The metabolism of water and salts. Water and mineral matter (inorganic salts) are as necessary constituents of food as proteins, fats and carbo-hydrates.

The maintenance of a normal water content in the organism is of great importance to the vital activity of the cells. Experiments performed with pigeons showed that a loss of 11% of water gave rise to certain disease symptoms in the bird, while a loss of 22% brought about death.

A person eliminates at least two litres of water daily by evaporation through the skin and through the lungs, and also with the urine and faeces.

In an ordinary diet, one gets a sufficient supply of mineral matter (especially of compounds of sodium, potassium, magnesium, calcium and iron), which are absolutely necessary for the organism. However, there is an insufficient amount of ***sodium chloride*** in food, especially in vegetable foods.

In certain diseases, the metabolism of the salts in the organism breaks down. Thus, in cases of anaemia, the content, in the organism, of *iron*, which enters into the composition of the red blood corpuscles, is usually lowered. In such cases, the physician often prescribes pills containing iron, and advises the patient to eat carrots, apples, cabbage, spinach and other foods rich in iron.

The regulation of metabolism. Certain facts concerning the influence of the nervous system on metabolism were known before Pavlov also. However, it was Pavlov who established firmly the scientific theory of the subordination of all the processes of metabolism to the nervous system. Such regulation Pavlov called *trophic*,[1] that is, regulation controlling the nourishment, the vital activity and the processes of metabolism of an organ.

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[1] from the Greek word "trophi" — nutrition, nourishment.

Destruction of trophic regulation accounts for the formation, in a dog, of ulcers on the skin of its extremities, in which all the efferent nerve fibres have been removed by means of an operation. In a human being, many diseases, connected with some disorder in the processes of metabolism, are the result of the destruction of trophic regulation.

The role of the cerebral cortex in regulating metabolism. K. M. Bykov and his co-workers, performing experiments on animals, as well as on people, have proved that the processes of metabolism may change under the influence of conditioned reflexes, that is, by the participation of the cortex of the cerebral hemispheres. The influence of the cerebral cortex accounts for the intensification of the processes of metabolism at the mere thought of doing physical work.

45. Nutrition norms

The calculation of the energy expended by the human organism. In order to establish nutrition norms, it is necessary to know how much energy is expended by the organism daily. There are several ways of doing that.

One of these methods is based on the principle that all the energy expended by the organism is finally turned into heat, in which form it may be determined and measured in calories.[1]

Another method of calculating energy expended is to determine the amount of oxygen absorbed by the organism. It is known that for each litre of oxygen absorbed, 5 calories are released as a result of the oxidation processes in the organism. If a person uses up 20 *l.* of oxygen in the course of one hour, the amount of energy expended will be equivalent to 100 calories. The total expenditure of energy a day will be $100 \times 24 = 2\,400$ calories.

The daily expenditure of energy. The amount of energy expended by the human organism depends, to a very great extent, upon the living conditions, the kind of work done and the amount, the weight of the body, the state of health, and many other things.

If a person lay quietly without making any movements whatever, he would expend one calorie per hour for each kilogram of his body weight. Taking an average weight of 60 to 65 *kgs.*, this would make a total of approximately 1 500 calories per day. A person who does little physical work and leads a sedentary mode of life, expends one and a half times more energy.

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[1] The amount of heat required to raise 1 *kg.* of water 1° centigrade (Celsius) is called a large calorie, or a kilogram-calorie.

A person doing mental work expends only a very little additional energy. In physical labour, the greater the number of muscles taking part in the movement of the body, the greater, in general, is the amount of energy expended. In physical work requiring an average amount of strain and an active mode of life, the expenditure of energy increases 2 — $2^1/_2$ times, reaching a total of 3000 — 3700 calories a day. In the case of very hard physical labour, the expenditure of energy may be still higher.

The impossibility of evaluating work on the basis of the energy expended. Scientists and practitioners have repeatedly attempted to evaluate the working activity of a person on the basis of the amount of energy expended, but such an evaluation is absolutely wrong. "Let them try," wrote Engels, "to express any kind of skilled labour in kilogram-metres, and let them attempt to determine wages on that basis!" Engels considered that the result of such an attempt "would be mere nonsense."

And, indeed, the expenditure of energy is connected mainly with muscle work, which is only one side of the labour process, that is, the class-conscious, socially useful activity of a person. To express the last in calories is impossible.

The calorie content of proteins, fats and carbo-hydrates. When the cells of the body assimilate proteins, fats and carbo-hydrates, they obtain from them a store of latent (potential) energy, which is released in the process of disassimilation. In order to determine the potential energy contained in nutritive material, it is necessary to know the amount of energy liberated during their oxidation.

Experiment has proved that in the oxidation of one gram of fat, approximately 9 calories are released. In the oxidation of one gram of protein or carbo-hydrate in our body, about 4 calories are given off.

The calorie content of a diet. The calorie content in the diet of a person should correspond to the amount of energy expended by him. The more energy he expends, the more he must receive. The daily diet of an adult person who does not perform much physical labour should contain, on the average, 3 000 — 3 500 calories.

The composition of a diet. For normal nutrition, it is necessary that the food should contain a sufficient quantity of all three types of nutritive material: proteins, fats and carbo-hydrates.

If a person confined himself to an exclusively carbo-hydrate and fat diet, completely devoid of proteins, he would inevitably die. Proteins are those building materials, without which the living matter cannot restore its daily losses.

Children, due to the fact that they are in the process of growth and that their weight keeps on increasing, need a greater amount of proteins for each kilogram of their body weight than adults.

The proportion of proteins, fats and carbo-hydrates in a diet should be, on the average, more or less constant. Any great changes in these proportions may lead to serious disorders in the organism. An exclusively protein diet, or an abundance of proteins, and also extremely fatty foods are, without any doubt whatever, harmful to the organism. Under ordinary conditions, an adult person must consume, approximately, the following daily proportions, in order to obtain 3000 calories:

proteins	100	grams
fats	60	„
carbo-hydrates	500	„

In strenuous work that requires a great expenditure of energy, the diet should be increased, with a proportional rise in the amount of each of the nutritive materials: fats, proteins and carbo-hydrates.

Under certain conditions it becomes necessary to increase the amount of one or another of the three basic nutritive materials in the diet. Thus, people in the far North feel an increased need for fats during severe frosts.

The degrees of ease with which foods are assimilated. The nutritive value of food depends not only upon its composition, but also upon the ease with which the nutritive material contained in the food is assimilated by the organism. The various kinds of proteins are not assimilated with the same degree of ease. In general, proteins of animal origin are utilized by the organism far more completely than proteins of vegetable origin. This is due to the following facts: firstly, proteins of vegetable origin are less easily digested, because they are contained in cells that have a thick covering of cellulose upon which the ferments do not act; secondly, proteins of animal origin are closer in composition to the composition of the proteins of the human body. Therefore, about half of the proteins composing a person's diet should be taken from foods of animal origin.

The ease with which foods are assimilated depends, to a great extent, upon the method of preparing them; thus, for example, mashed potatoes are assimilated more easily than boiled potatoes; while boiled potatoes are assimilated more easily than fried potatoes.

Approximately 90% of the food taken into the body is assimilated. This should be taken into consideration when composing a diet, the calorie content of which should always be increased about 10%.

46. Vitamins

The importance of vitamins. The organism needs not only proteins, fats, carbo-hydrates and salts, but also some other substances, called vitamins. Neither man nor animals can exist without vitamins.

An insufficient amount of vitamins leads to a sharp decline in the activity of the organism: metabolism breaks down, the labour capacity is diminished, fatigue rapidly sets in, there is a general weakening of the whole organism, and such serious diseases as rickets, scurvy, and others appear.

The properties of vitamins. The chemical structure of vitamins remained unknown for a long time, because even those foods that are most rich in vitamins contain them in very minute quantities. Moreover, the majority of vitamins are unstable substances. Many vitamins decompose either partially or completely when subjected to a high temperature or to the action of the sun's rays, or simply when kept for a long time.

However, during the last few years, research workers have succeeded in obtaining many vitamins in the pure state, and thus it has become possible to study their composition and properties. It has been determined that ferments and other important substances, which are very important for the maintenance of normal metabolism, are produced out of some vitamins in the organism.

Vitamins are produced in plants. The vitamins of plant food that are taken into the organism of an animal are stored up in small quantities in the various organs. The content of many of the vitamins found in foods of animal origin depends, to a great extent, upon the food the animal eats. Milk in summer is much richer in vitamins than milk in winter, because the cow feeds on fresh forage, while in winter it is fed on hay, which contains a smaller proportion of vitamins.

The different kinds of vitamins are designated by letters of the Latin alphabet.

Vitamin C. Many centuries ago it was known that epidemics of scurvy usually broke out in times of famine and also of war, especially among the populations of beseiged towns. *Scurvy* is a noxious disease. The symptoms are, first, a general weakness, fatigue, pain in the legs. Then gradually appear more serious symptoms of the disease: the gums begin to bleed; at first there are hemorrhages of a mild form in the skin, in the muscles and in the internal organs, then the hemorrhages become more severe; the blood-producing function of the bone marrow is destroyed, and a severe form of anaemia develops. However, patients quickly recover as soon as there is a possibility to add fresh vegetables and fruits to the diet.

The healing action of fresh vegetables and fruits depends on the content in them of vitamin C, which is found chiefly in living plant cells. Vitamin C is especially abundant in tomatoes, in the berries of sweet briar, in scallions, cabbage, spinach, black currants, oranges, lemons, tangerines, strawberries, gooseberries, raspberries, and several kinds of apples.

Vitamin C is the least stable of all the known vitamins. As a rule, vitamin C is partially or completely destroyed in foods that are dried or tinned, or in foods that are kept for a long time.

The human organism needs 0,1 gram of vitamin C a day.

Vitamin A. The lack of vitamin A, or an insufficient amount of it, in food, affects the sight, and causes a serious *eye disease*, which may result in blindness; changes take place in the epithelial tissues, for example, in the skin and in the mucous membranes, which make the organism more susceptible to contagious diseases and very sensitive to any kind of injury; in children, *stunted growth* is the result of the lack of vitamin A.

Cod liver oil contains more vitamin A than anything else; liver, butter, the yolk of an egg, are rich in vitamin A; the following plant foods are also rich in it: carrots, spinach, sorrel, scallions, red peppers, etc. To be more exact, plants do not contain vitamin A, but a substance that is similar to it, out of which vitamin A is produced in the animal organism.

An adult person should get about 5 *mg.* of vitamin A daily.

Vitamins of group B. What was formerly known as vitamin B was really a mixture of vitamins, some of which have been thoroughly investigated. Vitamins of group B are found in the seeds of grains and in the fruit of leguminous plants, in hazel nuts, and also in cabbage, potatoes, spinach, carrots, prunes and raisins. They are very abundant in barm. Of animal foods, the yolk of egg, caviar, liver, kidneys, heart, ham, milk are comparatively rich in vitamin B.

Some of the vitamins of group B serve as a source for the formation, in the organism, of certain ferments, which facilitate the normal functioning of the complex processes of metabolism.

The lack of vitamins in food, or an insufficient amount of them, brings about a serious breakdown in these processes.

In countries where the chief food of the population is rice, a certain disease by the name of *beri-beri* has long been known; (translated into English, beri-beri means "foot fetters"). This disease brings about weakness in the muscles, paralysis, and an extremely emaciated condition, of which the person suffering from the disease finally dies. The cause of the disease is the lack of one of the vitamins of group B, which is found only in the embryonic part of the seed of most grains. In polished grains (for example, rice), the embryo, rich in vitamins, is removed together with the covering and, as a result, a product is obtained that is well-polished, but devoid of any vitamin.

In our country there are only rare cases of beri-beri. However, any signs of fatigue, loss of appetite, a tendency to constipation and muscle weakness, show that there is a lack of this vitamin in the diet.

Retarded and stunted growth, certain eye diseases, the frequent appearance of breaks in the skin, disorders in the activity of the nervous system — all these are often caused by the lack of this or that vitamin of group B in the diet.

Problems. 1. Using the tables at the back of the book, make a list in your copy-book of foods from your own diet that are the chief sources of vitamin A, vitamins of group B and vitamin C (three for each).

2. Using the tables at the back of the book that give the composition of foods, make up an average daily diet for yourself or for a worker of some definite profession. Calculate the amount of proteins, fats and carbo-hydrates and calories in the diet you have composed; calculate separately the amount of proteins of animal and of vegetable origin. Give a detailed evaluation of the diet you have made up, and answer the following questions: a) Is there a sufficient amount of calories in the diet? (In order to answer this question, you must take into consideration the mode of life of the person for whom you have composed the diet, and the kind of work he does). b) Is there a sufficient protein, fat and carbo-hydrate content in the diet? c) Does it contain enough proteins of animal origin? d) Which of the foods that make up the diet are most rich in vitamins? Is there an insufficient amount of any of the vitamins in the diet?

47. The hygiene of nutrition

The importance of variety in food. The more appetizing and attractive the food, the more readily it is digested and assimilated. A varied diet is of great importance. One quickly tires of a monotonous diet, which fails to stimulate the appetite; as a result, the food is less easily digested. If the food is varied, there is pleasure in eating it; it is digested more easily and is, therefore, of greater use.

Moreover, if the food is monotonous, it is difficult to provide for the necessary proportions, in the diet, of all the nutritive materials and, especially, of vitamins.

Regimen of meals. Regular hours for one's meals are of prime importance. It is a very bad habit to eat the whole day's ration at one time; meals should be taken several times a day, approximately every four hours. In the intervals between meals, the food that is in the stomach passes into the intestinal canal, the stomach becomes empty, and the new supply of food that enters it is easily and quickly digested.

Adults, and also pupils of the upper grades at school, should eat four times a day. Two variants are suggested: 1) breakfast, lunch, dinner, supper; 2) breakfast, dinner, a light meal between dinner and supper, supper. The hours for taking one's meals may be arranged in accordance with the conditions of one's work, but once arranged, they should be strictly observed; moreover, supper should be taken at least one or two hours before going to bed.

The most hearty meal should be dinner, which should consist of about half of the whole daily ration of food. About one-fourth of the daily ration should be eaten in the morning, after getting up, before the working day begins. The last quarter is divided up between the two remaining meals.

Cleanliness. Cleanliness should be carefully observed during a meal. If this is not done, dirt and the microbes that dirt holds easily find their way with the food into the digestive organs, and are the cause of such noxious and dangerous diseases as typhoid, cholera and others.

Therefore, it is necessary to wash one's hands before each meal, and to see to it that the pots and pans and dishes are clean. Fruits and vegetables should be washed. One should drink only boiled water, or water that has been disinfected in some other way.

REVIEW QUESTIONS

1. Explain the process of metabolism and the transformation of energy in the human organism.
2. What is the role of the liver in metabolism?
3. How does metabolism change with over-indulgence in food and in cases of starvation?
4. How are the processes of metabolism regulated?
5. What is a calorie? How many calories does the oxidation of one gram each of protein, fat and carbo-hydrate produce in our bodies?
6. What is the daily expenditure of energy of people engaged in different activities?
7. What is the average daily requirement of proteins, fats and carbo-hydrates of the organism?
8. What are vitamins, of what importance are they in the organism, and what are the consequences of the lack of vitamins A, B and C in food?
9. What roles do ferments and vitamins play in metabolism?
10. What are the most important rules of the hygiene of nutrition?

VII. THE EXCRETORY ORGANS

48. The importance of the processes of excretion (elimination)

The end products of metabolism. Metabolism goes on continuously in each cell. The different compounds formed in the process of metabolism are finally converted into end products, which do not undergo any further changes in the organism.

Carbo-hydrates and fats consist of carbon, hydrogen and oxygen. As a result of their complete oxidation, ***carbon dioxide*** and ***water*** are formed in the organism, that is, the same substances that are formed during the simple combustion of carbo-hydrates and fats in the air.

Proteins are very complex in structure. In addition to carbon, hydrogen and oxygen, all proteins contain nitrogen, sulphur and, frequently, phosphorus and certain other elements. After the decomposition and oxidation of proteins have taken place in the organism, substances containing nitrogen (chiefly ***urea*** and ***uric acid***), ***salts of sulphuric acid*** and ***of phosphoric acid***, and some other compounds, are formed, besides carbon dioxide and water.

The waste products that accumulate in the cell have an injurious effect upon it. Their timely elimination is a necessary condition for the normal life activity of the organism. The cell eliminates the waste products into the medium surrounding it, that is, into the lymph of the tissues. From the lymph they pass into the blood.

The ways in which the products of metabolism are eliminated. The products of metabolism that accumulate in the blood are gradually discharged outside the organism.

In the human being, this is done chiefly through *the urinary organs*, which are special organs of excretion.

However, a part of the products of metabolism are eliminated also by other organs. Carbon is eliminated through *the lungs*; moreover, exhaled air is always saturated with watery vapours; about 400 *gr.* of water pass out through the lungs each day.

A large quantity of water is given off through the skin in the form of perspiration. Salts and a very small amount of the organic products of the metabolism of proteins are given off through *the skin*, together with the water.

The work of the excretory organs prevents the products of metabolism from accumulating in the organism, and at the same time helps to keep the composition of the blood constant.

49. The structure and work of the urinary organs

The structure of the kidneys. The kidneys (Fig. 92) are located at the back of the abdominal cavity, one on each side of the spinal column. They produce urine.

The kidney has two layers: an outer dark layer, and an inner light one. If we examine *the outer layer* with a magnifying glass, a great mass of dark little dots may be seen. These are little *bunches of capillaries*, called *glomeruli*, which lie in little cavities called *capsules*. Fine little *channels (tubules)*, which have their origin in the capsules, extend to *the inner layer*, and from there return to the outer layer. These little tubules unite with one another to form wider ducts, which pass through the inner layer of the kidney, and terminate in a cavity called *the pelvis of the kidney* (see coloured plate IV).

The formation of urine. Urine consists of *water*, holding in solution *inorganic salts, urea, uric acid*, and a number of other products of metabolism.

Some scientists considered the kidneys to be kinds of simple filters, and compared the process of urine formation with the process of filtration or diffusion. However, the process of urine formation was found to be much more complex than either filtration or diffusion, because it is connected with the activity of living cells.

As seen in table 2, some substances found in the blood — namely, proteins and sugars—are completely lacking in urine. The sodium content in both fluids — blood and urine — is nearly the same. Other substances are found in larger proportions in the urine than in the blood; however, the content of each of these substances in the blood and in the urine is definitely proportioned.

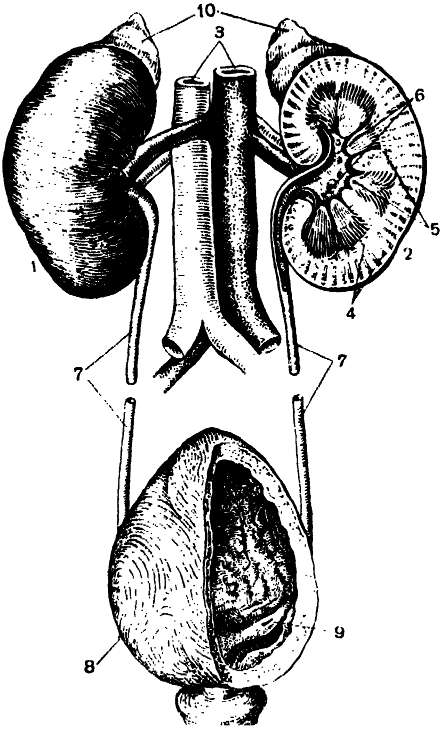

Fig. 92. Excretory organs:

1 — right kidney (as seen from the outside): left kidney (longitudinal section); *3* — blood vessels; *4* — outer layer of the kidney; *5* — inner layer of the kidney; *6* — pelvis of the kidney; *7* — uterus; *8* — urinary bladder with a part of its wall cut out so as to expose the opening of the ureter *(9)*; *10* — suprarenal glands.

It must be added that some substances introduced into the blood (methylen-blue, for instance) pass completely into the urine in a rather short time.

All this shows us how extremely complicated is the activity of the kidneys, which has not yet been thoroughly investigated up to the present time.

The process of urine formation begins in the glomeruli. Here the liquid part of the blood filters through the capillaries into the capsules. From the capsules, the liquid passes into the little tubules, where it undergoes considerable changes. All of the sugar contained in the liquid is absorbed by the epithelial cells of the tubules and passes back again into the blood. Several other substances, among them most of the water, are also partially re-absorbed, as a result of which the liquid in the tubules becomes

Table 2

Substances contained in the blood	The content of the same substances in the urine
Proteins	none
Sugar	none
Sodium	the same amount
Potassium	7 times more
Uric acid	12 times more
Urea	65 times more
Sulphates	90 times more

more concentrated. At the same time, a reverse phenomenon may be observed — the elimination of some of the substances from the blood into the tubules.

In its passage through the tubules, the liquid gradually changes in composition and concentration and is converted into urine.

The regulation of the formation of urine. The fact that certain substances found in the blood influence the formation of urine was known long ago. Some of these substances intensify the process of urine formation, while others weaken it. In addition to *humoral regulation,* there is also *nerve regulation* of the functioning of the kidneys. Nerve regulation can be easily studied by using the fistula method worked out by Pavlov (the method by which the ureter is conducted to the exterior of the body).

Bykov's work on dogs, with fistulae applied to their ureters, has proved that the activity of the kidneys is directed by *the cortex of the cerebral hemispheres,* and that it is possible to build up a conditioned reflex change in urine formation. It is well known that when water is introduced into the stomach, the urine formation is intensified reflexly. If this experiment (namely, the introduction of water into the stomach), is repeated many times, it will be found that the preparations alone, before performing the experiment, are sufficient to bring about a conditioned reflex increase in the activity of the kidneys. Bykov succeeded in building up urine secretion reflexes in response to various conditioned stimuli.

Urine excretion. The urine that is formed passes into the pelvis of the kidney, and from there into a long tube — *the ureter,* which unites the kidney with *the urinary bladder.*

In the wall of the ureter there are smooth muscle fibres, the contraction of which helps to move the urine onward.

The urinary bladder is situated in the lower part of the abdominal cavity. It has a thick muscle wall, during the contractions of which the bladder may be compressed and greatly dilated when filled with urine. In the lower part of the bladder there is a circular muscle which closes up the outlet of the bladder. The urine is expelled outside the body through *the urethra.* During urination, this circular muscle relaxes, while the muscles in the walls of the bladder, on the contrary, contract, thus driving out the urine to the exterior.

Urine excretion and, in particular, the act of urination, is regulated by the nervous system. The ability to urinate at will is due to the influence exerted by *the cortex of the cerebral hemispheres.*

REVIEW QUESTIONS

1. Enumerate the products of the decomposition and oxidation of fats, carbo-hydrates and proteins. Of what importance is their elimination from the organism and how does elimination take place?
2. What is the structure of the kidneys?
3. Explain the process of urine formation.
4. How is the activity of the kidneys regulated?

VIII. THE SKIN

50. The structure of the skin

The epidermis. The skin covers the outer surface of the body and protects the tissues of the organism from any external influence (Fig. 93).

The upper layer of the skin is called the epidermis, and is composed of many-layered (stratified) epithelium. In the deepest *basal layer* of the epidermis there is a single row of flat cells, packed close together; these cells grow and multiply unceasingly. The young cells, produced by the division of the cells in the basal cell layer, gradually spread over the old layer, replacing it, and pushing the old detached cells out to the surface.

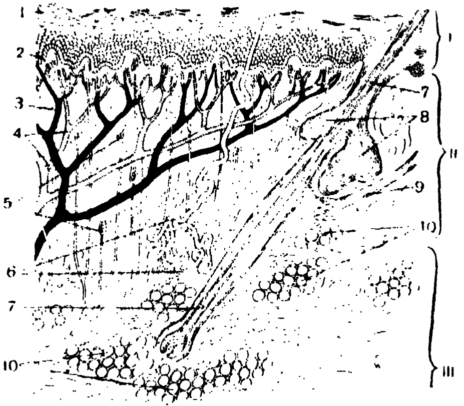

Fig. 93. Diagram of the skin structure:

I — epidermis; *II* — dermis; *III* — subcutaneous fatty tissue; *1* — horny layer of the epidermis; *2* — basal layer of cells of the epidermis; *3* — veins; *4* — arteries; *5* — sensory nerve endings; *6* — sweat gland; *7* — a hair; *8* — sebaceous or oil gland; *9* — a smooth muscle that raises the hair; *10* — aggregations of fat cells.

There are no blood vessels in the upper part of the epidermis. Blood vessels extend only to the basal cell layer, the cells of which easily get oxygen and nutritive material from the blood. The cells of all the other layers, and especially of the top layers of the epidermis, gradually degenerate and die. In this process of degeneration, the cells adhere closely to one another and are converted into a compact horny substance, which is constantly being shed from the surface of the skin in the form of white scales or flakes. Such flakes are most easily seen when they stick to the hair, — this is what everybody knows as dandruff.

The colour of the skin depends on the presence, in the cells of the epidermis, of a special colouring material — *skin pigment.*

True skin, or the dermis. The thicker central layer of the skin is known as true skin, or the dermis. The dermis consists of connective tissue, containing a great number of firm elastic fibres which give firmness and flexibility to the skin, so that it stretches easily with the movements of the body, and covers the whole body evenly and smoothly.

The dermis is richly supplied with blood and lymph vessels. The endings of the nerves, the roots of the hair, the sebaceous, or oil glands, and the sweat glands are also situated in the dermis.

The sebaceous, or oil glands. A sebaceous, or oil gland, resembling a small, sometimes branched sac, secretes oil, which forms a thin layer on the skin and the hair, thus keeping them soft to the touch and impermeable to liquids. Usually, as seen in figure 93, the ducts of the oil glands empty into *the hair follicles.*

Thin little bunches of smooth muscle fibres, situated near the oil glands and the hair follicles, contract and squeeze the oil out of the glands, thus raising the hair; then we say the hair "stands on end."

The sweat glands. A sweat gland has the appearance of a little tube coiled up in a knot; the cells of the sweat gland secrete sweat (perspiration). There are about two to three million sweat glands in the skin of a human being. The amount of sweat secreted is regulated by the nervous system. An example of this is the profuse sweat secretion that occurs reflexly when one takes a drink of water on a hot day; another example is the "cold sweat" that breaks out on the forehead when one is greatly frightened.

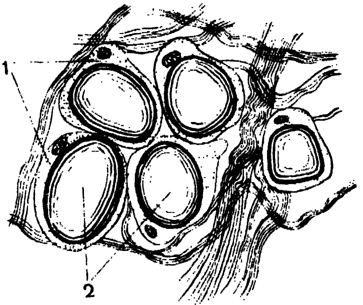

Fig. 94. Fatty tissue:
1 — fat cells; *2* — accumulation of fat within the cells.

Perspiration consists of *water*, holding in solution a small amount of *urea* and a few other products of metabolism; its salty taste is due to the presence of *inorganic salts*, especially of sodium chloride.

Subcutaneous fatty tissue. The lower layer of the skin covering is called the subcutaneous fatty tissue; it is several centimetres thick in some parts of the body.

The subcutaneous fatty tissue consists of cells that seize upon droplets of fat and store them in great quantity, so that they become almost completely filled up with fat (Fig. 94). This layer of the skin protects the internal organs against injury and minimizes the heat losses from the body. At the same time, it is the special place, in the organism, for the accumulation of stores of fat.

51. The importance of the skin

The permeability of the skin. The compact *horny layer* of the epidermis is saturated with skin oil and is impermeable to water and to the substances which the water holds in solution. Only a very few substances, dissolving the oil of the skin, may be absorbed in small quantities through the skin. Among these is aniline, used in the textile industry and in some other industries. When aniline comes in contact with the skin, it is absorbed by the skin and causes a severe case of poisoning. In the Soviet Union, therefore, the processes connected with the application of aniline have been mechanized, and a whole series of measures have been taken to safeguard workers against aniline poisoning.

The protection of the organism against injury. The compact layer of dead horny cells of the epidermis protects the layer of living cells under it; these living cells would be injured at the slightest contact with them, if they were situated on the surface of the body. On those parts of the skin that are subjected to greater irritation, — the soles of the feet, for instance, the horny layer of the skin may become very thick.

Callosities are thickened parts of the skin, especially of its horny layer, which have been subjected to constant rubbing or friction. Callosities are usually formed on those parts of the palm, which, in physical work, are liable to the greatest friction. Corns on the toes are the result of tight or poorly fitting shoes that constantly rub and irritate the toes.

The skin, with its subcutaneous fatty tissue, forms a thick, elastic layer, which receives the first shock of a blow or knock, and in that way protects the organs of the body.

Protection against the rays of the sun. The energy of the sun's rays stimulates the living cells and increases their activity. However, too great an exposure to the action of the sun's rays may interfere with the normal activity of the cells and even destroy them. The action of the invisible *ultra-violet rays,* which cause sunburn so easily, is especially strong.

The rays of the sun that reach the cells of the basal cell layer of the epidermis irritate them, thus forcing them to grow and to multiply more quickly. As a result, the epidermis becomes thicker and can hold the rays more easily, especially the ultra-violet rays, which penetrate the layer of horny cells with difficulty; the cells of the epidermis become rich in pigment, and the person is covered with *a coat of tan,* which also prevents the sun's rays from penetrating the skin, and thus protects the organism against the too strong action of the sun.

The stronger the action of the sun's rays on the skin, and the more prolonged the exposure of the skin to their action, the more tanned the skin becomes, and the thicker becomes the layer of horny cells in the skin.

Thus, sunburn and the thickening of the epidermis are defence reactions of the organism in response to the excessive action of the rays of the sun.

The excretion of the products of metabolism. In some animals — in the frog, for instance, a great part of the products of metabolism is excreted through the skin. In the human being, excretion through the skin goes on to a very slight extent, and does not play an important role. It is sufficient to say that about 95% of nitrogen in the form of urea, uric acid and other waste products is excreted through the kidneys, and only 5% through the sweat glands of the skin.

However, under certain conditions, especially when there is any disorder of the kidneys, the sweat may contain a much greater amount of the products of metabolism; thus, the sweat may perform the work of the kidneys that are not functioning properly. In such cases, the sweat acquires the smell peculiar to urine, and crystals of urea and of uric acid are deposited on the skin, as a result of the evaporation of sweat.

The maintenance of a constant temperature in the body. The temperature of the body of a healthy person is about 37°, and remains at that level at all times of the year and in all kinds of weather.

Heat is continually being produced in the body. An especially great amount of heat is produced by strenuous work of the muscles. The reason our bodies do not get over-heated is due to the fact that the loss of heat from the surface of the body goes on as continuously as the generation of heat in the body. The skin, which is in contact with the surrounding air, gives up heat to it, just as the surface of a heated stove gives up heat to the air — that is, by means of *conduction* and *radiation*.

The significance of the dilation and constriction of the capillaries in the skin. The skin is richly supplied with blood vessels. When the temperature of the air rises, the vessels of the skin dilate and fill up with a greater quantity of blood. The blood that rushes to the skin heats it up, and the heat is given off to the air through the epidermis much more quickly than under ordinary circumstances, when the vessels are not dilated.

The same thing occurs with muscle work, when it becomes necessary for the body to liberate more heat: the vessels in the skin dilate, the flow of blood is intensified, and a greater amount of heat is given off.

Conversely, when the temperature of the surrounding air falls, the vessels are constricted, and the heat loss through the skin is diminished.

Moist air is a better conductor of heat than dry air. Therefore, in cold, damp weather, the heat loss may be very great and the body may become greatly chilled in spite of the constriction of the blood vessels in the skin.

The dilation and the constriction of the blood vessels are controlled by the nervous system. The use of alcohol deadens the nerves that constrict the vessels, and the latter remain dilated and the skin hot even when the temperature of the air is low; in other words, the normal regulation of heat loss is destroyed. This explains why a drunkard usually does not feel the cold: he walks about on a cold day with his coat unbuttoned, and falls asleep untroubled in a frost. As a result of the intensified liberation of heat from his hot skin, the temperature of the drunkard's body is lowered, sometimes even several degrees, which may cause death. Thus, the belief that alcohol heats up the body is founded on self-deception.

The significance of sweat excretion. In hot weather, and also when working in hot workshops, where the temperature of the air is higher than that of the body, the dilation of the vessels in the skin cannot increase the heat loss: the extremely hot air does not cool off the skin, but, on the contrary, heats it up still more. In such cases, there is an intensified flow of sweat, which is evaporated from the surface of the body, thus preventing the organism from the danger of becoming over-heated.

The potential heat of vapourization is very great. Therefore, in evaporating, the sweat absorbs very much heat from the surface of the skin. As a result, the temperature of the body does not rise even when the temperature of the air is 40° or 50° above zero.

There is profuse sweat excretion, not only when the temperature of the surrounding air is high, but also when strenuous muscular work is performed.

The elimination of sweat is greatly diminished in cold weather and when the body is in a quiet state.

The changes in sweat excretion, brought about by the action of heat or cold on the skin, and also after taking a drink of water, *are unconditioned reflexes*. As an example of the influence of *the cortex of the cerebral hemispheres*, we may take the copious sweat secretion when one is frightened ("cold sweat"); another example is the intensification of sweat secretion as the result of a conditioned reflex when water is merely brought close up to the mouth.

The rate of sweat evaporation and, consequently, the magnitude of the heat loss, depend upon the temperature of the air, its motion, and the amount of moisture it contains. The warmer and dryer the air, the more quickly the sweat evaporates. On a windy day there is considerable sweat evaporation even if the air is moist. If there is no wind and the air is saturated with watery vapours, there is no sweat evaporation. This explains why it is so difficult to remain in a highly heated bath-house for a long time.

The over-heating and cooling off of the organism. Great as may be the ability of the organism to regulate the heat loss through the skin, still it has its limits.

When there is no wind, and the air is very hot and moist, the heat loss is greatly diminished; as a result, the body may become over-heated, and we say that the person has *a heat stroke*, which may cause death.

The chief symptoms of a heat stroke are: severe headache, nausea, and in more serious cases — loss of consciousness, convulsions. A patient suffering from a heat stroke should be carried at once to a cool spot, and some ice, or a towel soaked in cold water, put on his head; he should be fanned, so that the movement of the air might increase the evaporation of sweat; he should then be given plenty of cold or hot water to drink, in order to intensify the sweat excretion.

In cold, raw weather, the body may be chilled to such an extent that the organism is weakened and thus becomes more susceptible to disease. The organism may be weakened also by allowing separate organs of the body, especially the feet, to become chilled and to remain chilled for a long time. To walk about in wet shoes, or to go barefoot in cold weather when unaccustomed to it, are dangerous things to do, because the grippe, quinsy and even pneumonia may then be easily contracted.

Freezing. If the organs — especially those furthest away from the heart and so least of all supplied with blood — become cold, freezing may set in.

There are three stages of freezing: in the first stage, the frozen part of the body turns a dead white at first, and then becomes red and swollen. In the second stage, blisters are formed. In the third stage, blood circulation ceases, which results in mortification of the tissues; in such a case the skin turns black.

In the first stage of freezing, the first thing to do is to restore the circulation and bring about a flow of blood to the injured organ; this is achieved by energetic rubbing (best of all, with snow). In cases of more severe forms of freezing (the second and third stages) one must apply to a doctor.

Burns. In case of a slight burn, the burned part of the skin only becomes red. If the burn is more serious, the top layer of the skin peels off and a blister, filled with a light-coloured liquid, is formed. Very severe burns (of the third degree) result in mortification of the tissue.

There is danger in any kind of a burn that extends over a large part of the surface of the skin, because, firstly, all the necessary life functions of that large portion of the skin are destroyed, and, secondly, the organism becomes poisoned with the products of the decomposition and disintegration of the injured cells.

The skin may be burned not only by the action of heat, but also by the action of certain chemical substances (for example, sulphuric, hydrochloric, nitric and other strong acids, and caustic alkali), and also by such poisonous substances as mustard gas, lewisite and others, used in war.

Questions. 1. In what way may the heat loss be increased, if: a) the surrounding air is dry and its temperature is lower than that of the body? b) the air is saturated with watery vapours, and its temperature, as before, is lower than that of the body? c) the air is dry, but its temperature is higher than that of the body? d) the air is saturated with watery vapours and its temperature is higher than that of the body?

2. In which of the cases enumerated above is heat loss impossible by means of sweat evaporation, and in which cases is it impossible by means of the conduction of heat?

52. The hygiene of the skin

An unclean skin as the source of spreading disease. The organic substances which enter into the composition of the oil and perspiration of the skin, are readily decomposed; in the process of decomposition certain volatile substances are produced that have a very bad odour. Dirt that accumulates on the surface of the skin, especially in its numerous folds and creases, clogs up the openings of the oil glands and interferes with the process of sweat excretion.

Different kinds of microbes stick to the skin together with the dust particles; the products of decomposition eliminated by the skin provide a fertile field for such microbes to feed on and grow on.

The number of bacteria on the skin of people who are not clean in their person rises to tremendous proportions — as high as 40 thousand to the *sq. cm.*; on the whole surface of the body, with an area of 1,5 *sq. m.*, that would make about 600 million. Among these bacteria there are some that are harmless, but there are also some that are *piogeneous*, and during an epidemic there are others that serve as *the carriers of cholera, typhoid, dysentery.*

If cleanliness of one's skin and of one's clothing is not observed, parasites of various kinds make their appearance on the body. Some of them may be the cause of diseases of one kind or another. Thus, for example, itch-mites may get into the epidermis and, by forcing passages there in all directions, bring about a very unpleasant disease — *the itch.* Body-lice, living and multiplying in the folds of clothing, may be transferred from a sick person to a healthy one, and thus transmit a very serious disease — *typhus.*

On an unclean skin may often be found the eggs of *intestinal worms.*

By means of dirty hands, the agents of various contagious diseases may be transferred to food, and then get into the organism together with the food.

A slovenly person subjects others to danger as well as himself.

Cleanliness of the skin. In order to safeguard one's own health, as well as the health of those around us, it is necessary to keep the skin clean at all times.

One should wash one's whole body with hot water and soap at least once a week; the underclothing, which has absorbed the skin excretions, should be changed each time after taking a bath.

The face, neck and feet (especially if they are inclined to perspire) should be washed every day. Besides, the hands should be washed before each meal. Dirt collects easily under the nails; they should, therefore, be cut often.

The effects of an injured skin. Breaks, sores or ulcers may appear on the skin as a result of some injury to it. Certain harmful substances, or what is still more dangerous, disease-producing microbes may find their way into the organism through the affected part of the skin.

In all such cases, the organism responds by producing an inflammatory reaction. The blood vessels dilate; white corpuscles (phagocytes) pour out of them; the skin becomes red, swells a little and turns hot; often an abscess is formed.

When the inflammation begins to disappear, the pus that has gathered is eliminated. The cells of the connective tissue adjoining the injured part begin to multiply, and gradually draw the wound together. The remains of blood clots and of injured cells disintegrate and are devoured by the phagocytes. The surface of the wound is gradually closed up by the living and multiplying cells of the basal cell layer of the epidermis; over these new cells there soon appears a layer of horny cells.

The clothing. Clothing is a very important factor in the normal functioning of the skin. Clothing helps the organism to maintain a constant temperature.

When it is cold, clothing should diminish the heat loss. Therefore, the best materials for winter clothing are those that are porous (woollen stuffs, furs), since the air in the pores is a poor conductor of heat and does not allow much heat to be given up from the skin. When there are many layers of clothing with air spaces between the layers, the heat is given up more slowly and weakly. However, even in cold weather, too much clothing should not be piled on oneself, for the clothing may become a heavy weight for the body and interfere with the free movement of the body; besides, too much clothing may cause the body to become over-heated.

Conversely, when the temperature of the air is high, the clothing should help the organism to give up its heat. Therefore, summer clothing should be light in weight and as thin as possible; also, as few layers as possible should be worn in hot weather.

Summer cotton materials should be permeable to air and vapours, so that sweat evaporation may be facilitated and, as a result, more heat given off.

Underclothing, which comes in direct contact with the skin, should absorb the excretions of the skin well, and should be permeable to air. Soft material, which will not irritate the skin in any way, should be used for underclothing.

Outer clothing easily soils because of the dust in the air. Dust clogs up the pores of the material and thus increases its capacity as a heat conductor. Clothing may be kept clean by beating the dust out of them, and by brushing them regularly with a stiff brush.

Underclothing and one's dress or suit quickly absorb the sweat and oil secreted by the skin, or they become covered with the scales of the horny cells of the epidermis. Therefore, underclothing should be changed at least once a week.

The role of the skin in hardening the organism. The natural stimulators ot the skin — air, sun and water, make the skin less delicate, more capable of withstanding the changes in temperature, and keep it healthy and active.

Certain products of the metabolism of a healthy skin are increased in quantity when acted upon by these natural stimulators; such products of metabolism are absorbed by the blood and in their turn act upon all the organs of the body, and also upon the nervous system, increasing their activity. Besides this, the natural stimulators irritate the endings of the sensory nerves in the skin, and intensify the work of the body organs reflexly.

Therefore, air, sun and water have a beneficial effect upon the whole organism in two ways — by *humoral* regulation (through the blood) and by *nervous* regulation.

In order to attain perfect health and to increase the resistibility of the organism to various harmful influences, it is very important to harden oneself from childhood, and to utilize the natural stimulators of the skin rationally.

In summer one should take sun and air baths. In order to avoid serious sunburn, one must accustom the skin gradually to the action of the sun's rays. It is a good habit to go barefoot in summer. In the other seasons of the year, one should accustom oneself to wear as light clothing as possible. To muffle oneself up too much makes one delicate and more susceptible to disease.

The utilization of water is very important, and should not be limited only to bathing in summer. It is very important to rub or sponge the body every morning, all the year round, with water of room temperature, or to take showers if possible.

To stay in the water for a long time, or to take long sun baths, especially for people who are not accustomed to it, may have a harmful effect upon the heart and cause disorders in the nervous system. For some people it may be very harmful and dangerous to lie in the sun, to take cold showers and to do other things which are usually done to perfect the health. Therefore, any attempts to harden the organism must be done with the advice of a doctor.

REVIEW QUESTIONS

1. Describe the structure of the skin.
2. What is the protective role of the skin?
3. What is the role of the skin in hardening the organism?
4. How is the heat loss regulated through the skin?
5. Give the main rules for the hygiene of the skin.
6. What are the chief things to remember about clothing?

IX. INTERNAL SECRETION

53. Endocrine, or ductless, glands

Humoral regulation. Each organ secretes into the blood substances which can affect the activity of other organs. Thus, all the organs, depending upon the work they perform, secrete a larger or smaller amount of carbonic acid into the blood. The organism reacts to any change in the content of carbonic acid in the blood; the excitability of the respiratory centre is immediately affected. It is in this way that chemical, or humoral, regulation of respiration takes place.

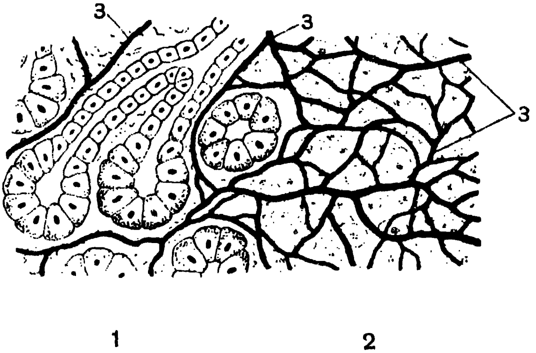

Fig. 95. Diagram of the structure of the pancreas:

1 — part of the pancreas that serves as an exocrine organ; 2 — part of the pancreas that serves as an endocrine organ; 3 — blood vessels.

The processes of metabolism that go on in the different organs vary; therefore, the chemical substances which the organs give up to the blood also vary. That is why the separate organs have different roles to perform in chemical interaction. Substances which take part in the humoral regulation of the process of digestion are absorbed by the blood from the walls of the stomach; the cells of the skin secrete, into the blood, certain substances which have rather a great influence upon the activity of the nervous system and of various organs of the body.

Hormones. The products of metabolism take part in humoral regulation in varying degrees. Some of the products of metabolism play such a dominating part in the regulation of the processes going on in the organism that their presence in the blood is absolutely essential for the maintenance of life. These substances have received the name of hormones.[1]

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[1] From the Greek word "hormao", which means "I excite" or "I arouse."

As a rule, hormones are highly active substances. Although their quantity in the blood is insignificant and hardly perceptible, they, nevertheless, exert a great influence on the various processes which go on in the organism. In this respect, hormones may be compared with vitamins. However, there is a basic difference: vitamins enter the organism together with the food, while hormones are produced within the organism itself. Certain vitamins serve as material for the formation of hormones.

Adrenaline and acetylcholine are hormones which participate in the humoral regulation of the blood circulation. Both of these hormones have been thoroughly investigated; not only has their chemical formula been determined, but it has become possible to produce them in the laboratory by means of synthesis. It has also become possible to produce other hormones by chemical means.

However, at the present time, little is known as yet about the composition and structure of certain hormones. Secretin, for example, formed in the wall of the duodenum and causing the secretion of pancreatic juice, is one of these hormones.

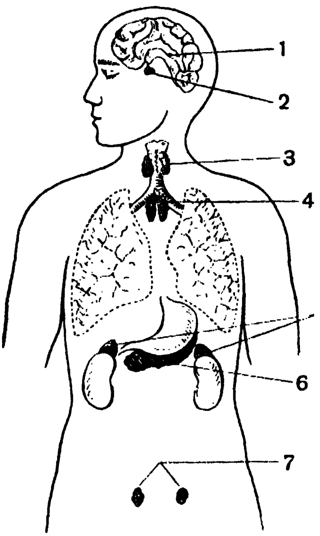

Fig. 96. Location of the most important endocrine glands:

1 — pineal body; *2* — pituitary gland (hypophysis); *3* — thyroid gland; *4* — thymus gland; *5* — suprarenal glands; *6* — pancreas; *7* — sex glands.

The exocrine and endocrine (or ductless) glands. Such glands as the salivary, gastric and sweat glands have excretory ducts, through which the juices, or *secretions*,[1] that they produce, are eliminated. Gastric and intestinal juice are eliminated into the cavity of the alimentary canal; perspiration and skin oil are eliminated onto the surface of the body. Glands supplied with excretory ducts are called exocrine glands (glands of external secretion).

Glands in which hormones are produced are called endocrine, or ductless, glands (glands of internal secretion). These glands have no excretory ducts and eliminate the substances they produce directly into the blood and lymph.

We can see, at once, the great difference in structure between the endocrine and the exocrine glands, if we examine the pancreas under the microscope (Fig. 95). Some parts of this organ are supplied with excretory ducts and produce pancreatic juice, which passes into the duodenum. Others, called *islets*, are endocrine glands. They have no excretory ducts and are very richly supplied with blood vessels. The hormone, insulin, that is produced by the cells of these islets, accelerates the transformation of grape sugar into animal starch, and passes directly into the blood.

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[1] From the Latin word "secretio", which means "I eliminate".

The locations of some of the most important endocrine glands are shown in figure 96.

54. The thyroid gland

The location and structure of the thyroid gland. One of the endocrine glands that has undergone a most thorough investigation is the thyroid gland. It is located in the neck, a little below the thyroid cartilage of the larynx (Fig. 97). Groups of cells of this gland form vesicles, or alveoli, which, unlike the alveoli of the salivary gland, have no excretory ducts. The space inside the alveoli fills up with a viscid, mucus-like fluid, which contains the hormone of the thyroid gland. The quantity of this hormone found in people varies: in some people the thyroid gland is over-active; in others, its activity is deficient. Observations of patients with thyroid glands which do not function properly, and also experiments made in removing the gland from animals and in grafting it, have helped to clarify the role of the thyroid gland in the organism.

Over-activity of the thyroid gland. The thyroid gland of some people becomes enlarged and produces too much hormone. The alveoli become very much dilated due to the fluid that accumulates in them, and, as a result, the gland increases in size. Over-activity of the thyroid gland may give rise to a serious disease called *Basedow's disease.*

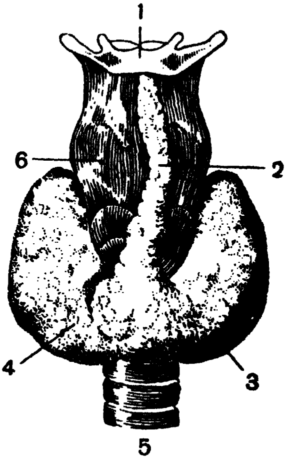


Fig. 97. Thyroid gland of a human being:

1 — hyoid bone; *2* — middle lobe of the thyroid gland; *3* and *4* — right and left lobes; *5* — windpipe; *6* — thyroid cartilage.

In cases of Basedow's disease, metabolism is greatly intensified. The need for oxygen is very much increased even when the patient lies quietly. The heart beats are violent and very frequent. The patient is always in a highly excited state, reacts very strongly to everything, is easily irritated, and usually suffers from insomnia. Other symptoms of this disease are abnormal protrusion of the eye-balls, an increasing weakness of muscle activity and a rapid loss of weight, which often leads to a state of complete emaciation.

Deficient activity of the thyroid gland. One of the constituents of the hormone of the thyroid gland is iodine. The slight amount of iodine which drinking water and food usually contain is quite sufficient for the normal functioning of the gland. However, in some localities, chiefly in the mountainous regions of the Urals, the Caucasus and of Central Asia, the soil and the water and, therefore, also the plants, are practically lacking in iodine; as a result, people living under such conditions have an insufficient amount of iodine in their organism.

The thyroid gland reacts to this lack of iodine by increasing its own activity. The glandular tissue becomes enlarged, and the cells produce an increased amount of the mucus-like fluid which dilates the alveoli. As a result, *a goitre* develops, and the weight of the gland is increased, sometimes to 4 or 5 *kgs*.

In spite of the tremendous enlargement of the gland, the amount of hormone it produces not only does not go beyond the normal, but even falls a little below the normal. However, a goitre, in the majority of cases, is not accompanied by any disease symptoms.

Sometimes there is complete or partial inactivity of the gland. This brings about a disease known as *mucus oedema*, or *myxoedema*. Children suffering from this disease are stunted in growth. The subcutaneous connective tissue swells and begins to degenerate, which gives the skin an inflated appearance; the eyes are just barely open, the mouth is large and often the tongue hangs out of it. The activity of the whole organism slows down abnormally: the heart beats occur less frequently than in healthy people, the temperature of the body is lowered, the work of the digestive organs is sluggish. With time such children turn into deformed idiots, incapable of performing any work. They usually do not live long, and die when quite young.

If an adult person suffers from mucus oedema, it does not affect his growth, of course, but all the other phenomena are the same as those observed in children. Unnatural obesity also appears, the face and body become swollen, higher nervous activity is disordered, the person loses all interest in what is going on around him, the memory becomes weakened, and the mental activity is greatly diminished.

The removal and grafting of the thyroid gland. The removal of the thyroid gland in animals — dogs, for instance, — gives rise to the same phenomena as observed in people suffering from mucus oedema. The animal becomes dull and sluggish, the body swells up, there is a lack of appetite, anaemia begins to develop and the whole organism becomes emaciated. If the thyroid gland of young animals is removed, retarded growth is an additional feature observed (Fig. 98).

But if only a part of the thyroid gland is left — no matter how small that part may be — the symptoms described above either do not appear at all, or if they do appear, it is in a very mild form.

These symptoms also disappear if a part of a gland from another animal of the same species, or of a species closely related to it, is grafted in the animal whose gland has been removed. The grafted piece of a gland often takes root and continues to fulfil its usual functions. Moreover, it makes no difference where the gland is grafted — in the place of the removed gland or in some other place. Grafting is often done in the abdominal cavity.

Similar improvement may be observed by mixing extracts of the gland of another animal, or pieces of a gland, with the food given to the animal whose thyroid gland has been removed.

The influence of the thyroid gland on development. The hormone of the thyroid gland is one of the most important regulating agents in the development of the organism. When the thyroid gland of a tadpole is removed, its metamorphosis, that is, its transformation into a frog, is greatly retarded. On the other hand, when a preparation of the thyroid gland is added to the water in which the tadpole lives, the metamorphosis is considerably accelerated.

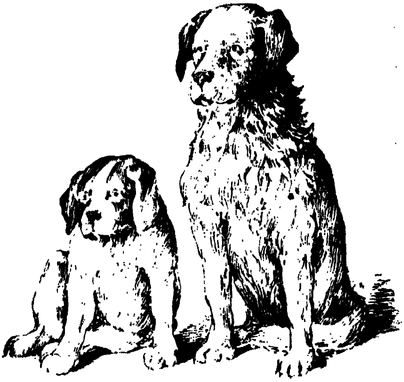


Fig. 98. Two adult dogs of the same litter. The thyroid gland was removed from the dog on the left when it was three months old.

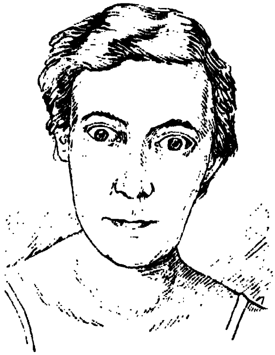


Fig. 99. A woman suffering from Basedow's disease.

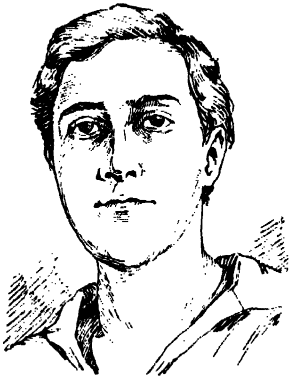


Fig. 100. The same woman after a part of the thyroid gland was removed.

Phenomena which are observed in animals at certain seasons (the shedding of the skin by reptiles, or of feathers by birds and others) also depend, to a very great extent, upon the hormone of the thyroid gland.

The treatment of diseases of the thyroid gland. When there is a lack of activity of the gland in the organism, the hormone that is lacking is introduced into the organism. Thus, powders or pills, prepared out of the ground-up thyroid glands of animals, are prescribed for internal use. But patients must continue taking these preparations all their lives, just as the short-sighted person must always wear glasses, and the lame person must always use crutches.

Sometimes good results are obtained, although temporary ones, by grafting in the patient the gland, or a part of the gland, taken from a still fresh corpse or from an animal that is most closely related to man — the monkey. However, in most cases, the grafted gland gradually resolves and disintegrates, and in several months symptoms of the disease appear again.

In cases of over-activity of the thyroid gland, surgeons sometimes remove a part of the gland, and then the disorders, which arose in the organism because of the excessive amount of hormone, disappear (Fig. 99 and 100).

55. The pituitary gland, or the hypophysis

The pituitary gland, or the hypophysis, is located on the lower surface of the brain, not far from the outlet of the optic nerves. A whole series of hormones, which regulate the various processes of metabolism, are produced in the pituitary gland.

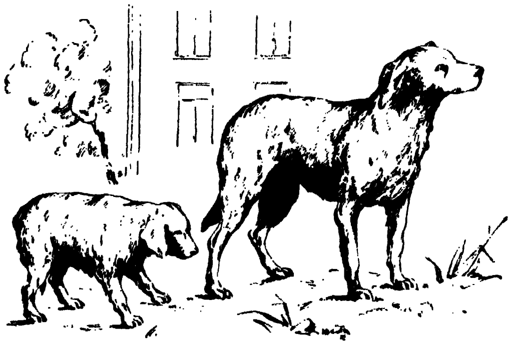


Fig. 101. Two dogs of the same litter; the pituitary gland was removed from the dog on the left.

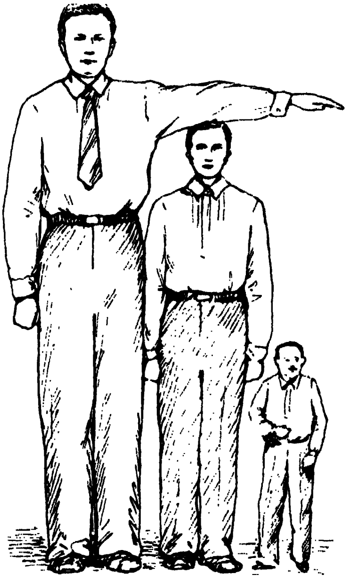
One of the hormones of the pituitary gland affects the growth of the young organism, and especially the growth of its bones (Fig. 101). Deficient activity of the pituitary gland is the cause of retarded growth in children. So great may the retardation be that such patients, on reaching the adult state, are often not more than 70 or 80 *cm.* in height, which is just half the height of a normal person. People of such abnormally small stature are called *dwarfs* (Fig. 102).

If the pituitary gland is over-active, a reverse phenomenon may be observed.

The child begins to grow abnormally fast and assumes giant-like proportions — two metres or more in height. Such *giants* have been known to grow to a height of 265 *cm.* (Fig. 102). In spite of their great height, giants are not any stronger than normal people; usually they are much weaker.

In adults, the excessive activity of the pituitary gland gives rise to a very noxious disease — *acromegaly.* As a result of the unnatural growth of the separate parts of the body in this disease, the arms and legs especially become abnormally long, the thorax swells out, and the bones of the face become enlarged, particularly the lower jaw and the nose. The tongue sometimes becomes so enlarged that the mouth cannot hold it. The body takes on a deformed appearance. This disease is also accompanied by a number of internal disorders, and usually results in death.

Attempts of surgeons to remove the diseased gland by means of an operation have given very poor results: the patients became much worse and, in many cases, died.



ig. 102. The influence of the hypophysis upon growth: in the middle — an adult of average height; at the left — a giant (excessive functioning of the hypophysis); at the right — an adult dwarf (deficient functioning of the hypophysis.)

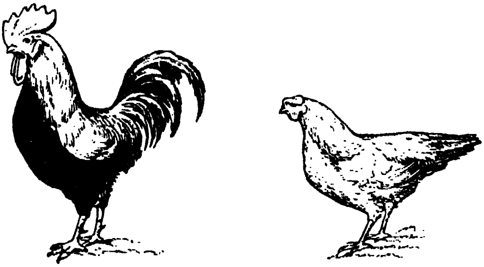
56. The sex glands

The removal of the sex glands. The male sex glands are called *testes,* and the female — *ovaries.* The testes and ovaries secrete hormones into the blood, and must therefore come under the head of endocrine glands (glands of internal secretion).

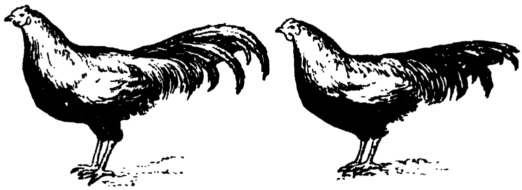
Even in ancient times it was known that the sex glands exerted a great influence on the general development of the whole organism. Removal of the sex glands, or *castration,* brings about profound changes in the organism.

If a young animal is castrated, the secondary sexual characters, that is, the external peculiarities of structure of the male and female organism, are not developed. Thus, for example, if a cock is castrated, the plumage that is characteristic of him does not develop, neither does his comb become enlarged. A hen with her ovaries removed loses those features peculiar to a hen, and becomes very similar in appearance to a castrated cock (Fig. 103). Moreover, castration of animals gives rise to a large accumulation of fat in their bodies.

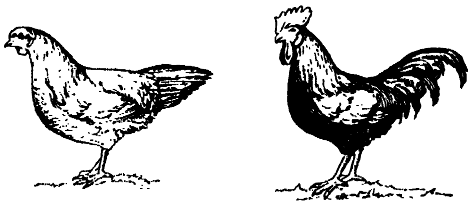
Ages ago, people made use of castration for economic purposes. If the testes of a bull are removed, a peaceful bullock is obtained that can then be readily utilized for agricultural work. Cocks and boars are castrated to obtain fat meat for the table.



A normal cock *A normal hen*



A castrated cock *A castrated hen*



A castrated cock with grafted ovaries *A castrated hen with grafted testes*

Fig. 103. Experiments in removing and grafting sex glands.

In some countries, the testes of men are removed out of religious motives, and as a result, such men are maimed for life. If the operation is performed in childhood, ***the secondary sexual characters*** fail to develop: neither a beard nor mustaches grow; all his life the person retains the high-pitched voice characteristic of children; the skeleton, and especially the pelvis, retains the form peculiar to children; a comparatively large layer of subcutaneous fat appears. Castration has a very great effect also upon higher nervous activity; this is reflected in the whole behaviour of a person. Extreme sluggishness and laziness, cruelty and selfishness make their appearance very soon, and are highly characteristic traits; vigour and active thinking are gone for ever.

Grafting of sex glands. The effect which the sex glands have on the development of the secondary sexual characters may be clearly seen in experiments with the grafting of glands of the opposite sex in castrated animals (Fig. 103). When ovaries are grafted in a castrated cock, the cock develops the secondary sexual characters of the female, and is like a hen in appearance; on the other hand, if testes are grafted in a castrated hen, the hen assumes the appearance of a cock.

Similar artificial "sex transformations" have been produced in some other animals. These experiments have definitely established the fact that the development of the secondary sexual characters is closely connected with the internal secretion of the sex glands.

The hormones of the sex glands. The hormones of the testes and of the ovaries have been thoroughly investigated. They are very similar in their chemical structure. However, it has been proved by experiments in removing and grafting sex glands that male and female hormones have quite different effects upon the organism, and that each helps to develop only those secondary characters which are peculiar to its own sex.

Besides the hormone which conditions the development of the secondary sexual characters, the ovaries produce a hormone which is absolutely necessary for the normal development of *pregnancy* and of *the mammal glands.*

Problem. Using the following diagram, compose a table of endocrine glands that are known to you:

Name of the gland	The changes which take place in the organism when there is —	
	over-activity of a gland	deficient activity of a gland, or when it is removed

§ 57. The importance of endocrine, or ductless, glands

The interrelation between the endocrine glands. Each endocrine gland, secreting the products of its own activity into the blood, takes a definite part in the regulation of the processes of metabolism. In so doing, the various glands exert an influence on one another, and thus a close interactivity is established between them. For example, one of the hormones of the pituitary gland increases the activity of the sex glands; if the pituitary gland is removed, the production of sexual hormones ceases very quickly. The hormones of the sex glands, in their turn, influence the function of the pituitary gland by lowering its activity.

It is an established fact that the sex glands and the thyroid gland act reciprocally upon each other; at the same time, the work of the thyroid gland is under the strict control of one of the hormones of the pituitary gland.

These examples show how complicated are the conditions under which the chemical regulation of the life processes takes place. By means of their hormones, the endocrine glands regulate not only the activity of the various organs of the body, but also one another.

The destruction of the normal work of one gland immediately affects the functions of the others. This, in its turn, gives rise to a number of changes in the organism and leads to disorders which may be very complex and varied.

The regulation of internal secretion. The work of the endocrine glands, like the work of all the other organs of the body, is regulated by the nervous system. Experiments show that the irritation of a nerve which leads to an endocrine gland intensifies the formation of a hormone. Thus, for example, the irritation of *the vagus nerve* intensifies the secretion into the blood of the hormone of insulin, which is produced by the islets of the pancreas. These reactions are of a reflex character.

Changes in the work of the endocrine glands, brought about by conditioned stimuli, prove that the activity of these glands is controlled by *the cortex of the cerebral hemispheres.*

On the other hand, facts concerning the influence exerted by hormones (for example, by the hormone of the thyroid gland) on the functioning of the brain and, particularly, on the work of the cortex of the cerebral hemispheres, have been known for a long time. Consequently, the nervous system and the endocrine glands have a reciprocal influence upon each other. However, the leading role is still played by the nervous system. The subordination of the activity of the endocrine glands to the nervous system and, especially, to the cortex of the cerebral hemispheres, makes it easier for the organism to adapt itself to the ever changing conditions of the external environment.

The practical application of hormones. The great success achieved in the study of the endocrine glands have made it possible to fight many diseases that were considered incurable before. Thus, for example, all the disease manifestations that arise when the thyroid gland stops functioning may be completely liquidated by the regular use of preparations of this gland.

No less important is the successful utilization of different hormones for economic purposes. By introducing certain hormones into the organism of an animal or, on the contrary, by removing certain endocrine glands, we are able to *direct* the development of an animal in a way that is desired by us. Thus, the castration of animals brings about the accumulation of a great amount of fat in their bodies, and makes them quiet and obedient. By means of hormones, the growth of animals may be accelerated, the amount of fat meat increased, egg-laying increased and the quality of eggs improved; hormones influence the fertility of animals, the development of feathers, wool, etc.

REVIEW QUESTIONS

1. How is the humoral interaction between the organs accomplished?
2. How do the endocrine glands differ from the exocrine glands?
3. What glands secrete internally and externally at the same time? Explain the internal secreting function of these glands.
4. What are the chief methods of studying the activity of the endocrine glands?
5. What is the role played by the thyroid gland?
6. How does the pituitary gland (hypophysis) influence the functions of the organism?
7. What is the role of the hormones of the sex glands?
8. What are the methods of treating diseases caused by disorders in the activity of the endocrine glands?
9. What are the practical applications in medicine and in agriculture of our knowledge of the endocrine glands?

X. THE NERVOUS SYSTEM

58. The importance of the nervous system

The reaction of the organism to the environment. The organism would not be able to exist were it not for its interaction with the external environment. The organism reacts to the most varied changes that go on around it, providing those changes are of sufficient force. Moreover, a reaction is not limited to those organs which receive a given stimulus directly — it spreads to the whole organism. The sudden tooting of an automobile horn irritates only the sensitive cells of the organ of hearing. However, the reaction to that sound may be very complex: the person responds with certain movements; for example, he turns in the direction of the noise; the rate of his heart pulsations begins to increase; the secretion of digestive juices is retarded, etc. We have already discussed similar, general reactions of the whole organism in the study of the digestive organs, the respiratory organs and others.

Reactions of the organism may also be brought about through the medium of the fluids of the body, that is, by humoral means. Thus, due to the action of ultra-violet rays on the skin, substances are produced in the skin which get into the blood and accelerate the processes of metabolism in the various organs of the body. However, the rapid and varied responses of the organism to changes in the environment cannot be provided for in this way. To bring about these and all other reactions requires the absolute participation of the nervous system. The same ultra-violet rays stimulate the nerve endings of the skin; the impulses pass on to the central nervous system, and from there, along the efferent nerve fibres, are directed to the various organs, producing changes in their activity.

In the higher animals, and especially in the human being, the nervous system is of the greatest importance in bringing about the reactions of the organism to the external environment. It is through the nervous system that the organism is able to orientate itself in the world surrounding it and to adapt itself to the ever changing conditions of life.

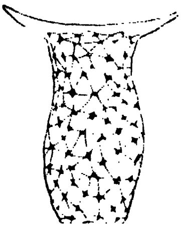


Fig. 104. Diagram of the structure of the nervous system of a hydra.

The general structure of the nervous system. All multi-cellular animals, with the exception of the sponge, have a nervous system. Animals of the coelenterata group (the hydra, for example), have a nervous system that looks like a net spread over the whole body, and that is composed of cells, connected with one another by means of branching projections (Fig. 104). In such a nervous system excitation spreads quite evenly in all directions; therefore, one and the same motor reaction will be obtained in response to a stimulus applied to any part of its body — namely, all the muscle cells will contract. In accordance with this, the behaviour of the hydra is also of one and the same character.

In proportion as the animal world developed, the structure of the nervous system kept on changing and increasing in complexity; and with the increasing complexity of the nervous system, the reactions of the organism became more and more complex and varied.

All vertebrates, including man, have a central nervous system and a peripheral nervous system (see coloured plate V).

The central nervous system is a vast aggregation of nervous tissue and consists of *the spinal cord,* situated within the spinal column, and *the brain,* contained in the cranial (or skull) cavity.

The numberless *nerves* that extend from the spinal cord and the brain compose *the peripheral nervous system.* In various parts of the peripheral nervous system there are small aggregations of nerve cells — *the ganglia.*

Coordination of the activity of the body organs. All the reactions of the organism are always strictly correlated and coordinated because they take place with the participation of the nervous system. Thus, the bending (flexing) of the arm at the elbow is the result of the coordinated activity of a whole group of muscles: the flexors contract; moreover, each of them, in each separate case, contracts with a definite force; the extensors relax (extend) simultaneously; the extent to which each of them relaxes is again strictly determined. More than that, a change in the state of each muscle is accompanied by the dilation or constriction of its blood vessels. Consequently, the simple motion of bending the arm is accompanied by a whole series of correlated and coordinated changes in the organism.

The nervous system regulates the activity of all the organs, and is constantly adjusting their work to the needs of the organism. As a result, there is strict coordination, not only in the contraction of muscles, but also in the functions of the internal organs.

The role of the brain in the perception of the surrounding world. A person receives sensations and gets a perception, or knowledge, of the world surrounding him through the medium of the sense organs and of the nervous system. All human *thought* and *behaviour* are connected with the activity of the nervous system. Thought and consciousness, in the words of Engels, are "the products of the human brain."

59. The structure and properties of the nerves

Nerve fibres. A neuron consists of *the body* of the cell, of short branching projections, or *dendrites,* and usually of one long projection, or *axon*. The long projection (axon), together with the sheath in which it is enclosed, is called *the nerve fibre.*

If we take a cross-section of the brain or of the spinal cord, we may see that in some places the material of the brain and of the spinal cord is of a dark colour — the so-called *gray matter,* and in others it is of a light colour — *the white matter.* The gray matter consists, primarily, of a vast number of nerve cells. Nerve fibres, extending from these cells and covered with a white sheath, are collected together in a compact mass and form the white matter of the brain (Fig. 105).

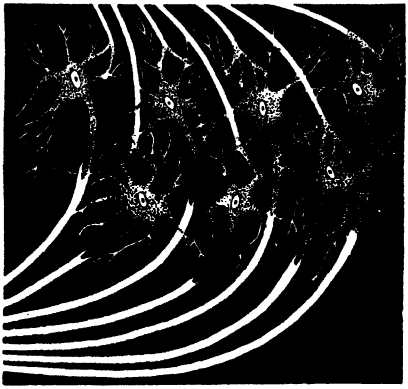


Fig. 105. Nerve cells (gray matter) and nerve fibres (white matter).

The structure of the nerves. A nerve is made up of a great number of *nerve fibres,* which differ from one another chiefly in the thickness of their white sheaths. The separate bundles of nerve fibres, and also the nerve as a whole, are enclosed in a sheath of connective tissue (Fig. 106).

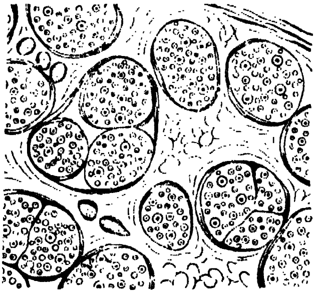


Fig. 106. Cross-section of a nerve; bundles of nerve fibres of varying thickness are seen.

A little above the point of its own ending, the nerve fibre loses its white covering and breaks up into several branches, which lead close up, either to the muscle fibres, to the cells of a gland or of some other organ, or, finally, to the dendrites of another neuron.

The conduction of excitation along a nerve. The chief property of the nerve tissue is the conduction of excitation.

If a muscle, together with the nerve leading up to it, is cut out of the body of a frog and a stimulus is applied to the nerve (an electric current, a chemical substance, or pinching it), the muscle will contract. This occurs because the excitation aroused in the nerve travels along the whole length of the nerve and is transmitted from the nerve endings to the muscle fibres. However, if the nerve is deadened at any point with alcohol or chloroform, or if it is tied up tightly at any point with a thread, the transmission of excitation through the injured or affected part will cease: there will be a contraction of the muscle only when the part of the nerve that is between the deadened section and the muscle is stimulated. (Fig. 107).

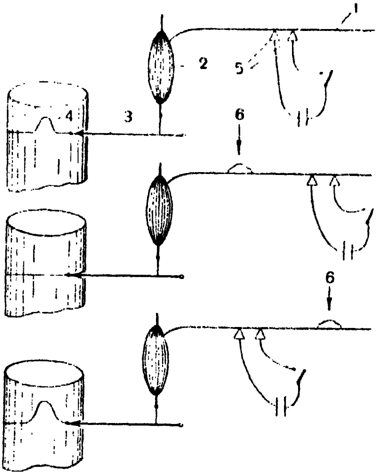


Fig. 107. Diagram of the conduction of excitation along a nerve:

1 — nerve; *2* — muscle; *3* — lever for producing the records on the kynograph; *4* — muscle contraction recorded on the kymograph; *5* — electrodes for stimulating the nerve by means of an electric current; *6* — a piece of cotton wool soaked in chloroform and applied to the nerve. The impulse cannot pass through the injured part of the nerve.

The conduction of excitation as a physiological process. The conduction of excitation is an extremely complex physiological process. It has nothing in common with the passage of an electric current along a conductor. An impulse is conducted along a nerve at the rate of 20 to 30 or more metres a second; in the human being, the rate of conduction may rise as high as 100 or 120 *m*. An electric current, however, spreads along wires with the speed of light, travelling about 300 000 *kil.* per second.

Although the process of excitation spreads much more slowly than an electric current, yet the speed with which a nervous impulse is conducted is such that the reactions of the organism may be felt in several tenths and even hundredths of a second.

60. The spinal cord

The structure of the spinal cord. The spinal cord is located in the vertebral canal, which is formed by the bodies and by the arches of the vertebrae (Fig. 108). It extends along the length of the vertebral canal in the form of a thick cord, and is divided by two *fissures* into *right* and *left halves*.

In the very centre of the spinal cord there is *a canal,* which passes into the brain. This canal is filled with a liquid, similar in composition to lymph.

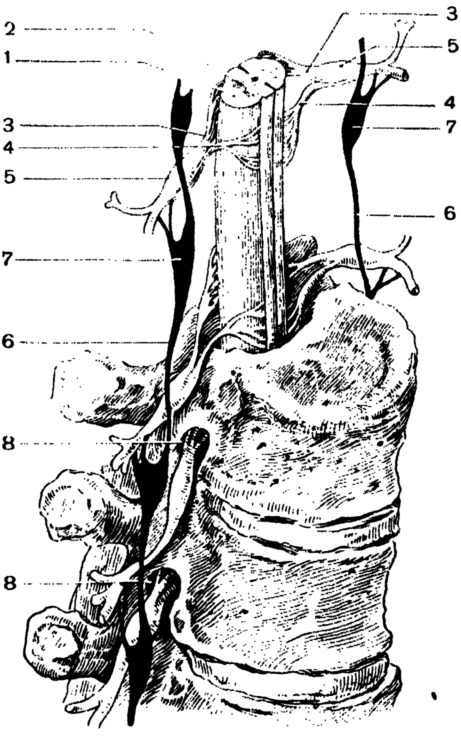


Fig. 108. Spinal cord:

1 — white matter; 2 — gray matter; 3 — posterior spinal nerve root; 4 — anterior spinal nerve root; 5 — intervertebral ganglion; 6 and 7 — sympathetic trunk; 8 — intervertebral opening.

The white and the gray matter of the spinal cord. If we examine a cross-section of the spinal cord, we may see that *the gray matter* is in the interior of the cord and that *the white matter* surrounds the gray.

Those parts of the gray matter which, when irritated, bring about activity in the various organs, were conventionally named *the nerve centres* of these organs. Thus, for example, the nerve centre of the diaphragm is located in the spinal cord at the neck; if this part of the spinal cord is destroyed, the diaphragm ceases to contract. The nerve centres of the muscles of the trunk of the body and of the upper and lower extremities, and also the nerve centres of the internal organs, are located in the gray matter of the spinal cord.

The main mass of the white matter consists of nerve *fibres,* which unite the various centres of the spinal cord with each other, and which also run from the spinal cord to the different divisions of the brain, or, vice versa, from the brain to the spinal cord. The nerve fibres that unite the various sections of the brain, are called *conducting pathways*. Through them *connection* is set up between the neurons of the different divisions of the brain, and thus *the integrated* and *coordinated activity* of the whole nervous system is provided for. The brain regulates the work of the spinal cord, and at the same time receives impulses from it which largely determine its own activity.

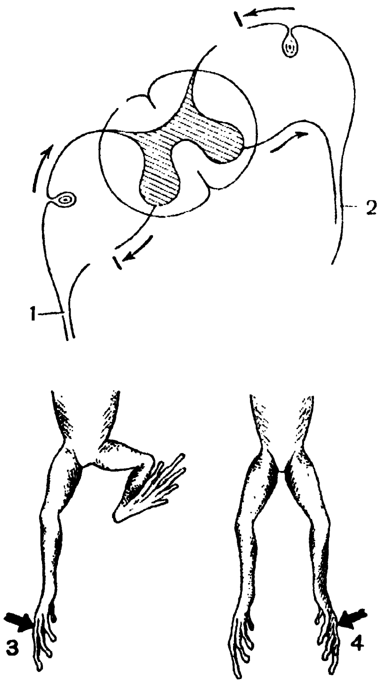


Fig. 109. Diagram of an experiment with a cross-cut of the roots of the spinal nerves (the right anterior and the left posterior spinal nerve roots are cut):

1 — nerve of the right hind leg; 2 — nerve of the left hind leg; 3 — irritation of the right leg; 4 — irritation of the left leg.

The spinal nerves. *The spinal nerves* issue from the spinal cord, to the right and to the left of it, between each pair of corresponding vertebrae; in all there are 31 pairs of spinal nerves. Each nerve originates from the spinal cord by two *roots — the anterior* and *the posterior.*

Let us say that all the anterior *roots* on the right side of a decapitated frog, and all the posterior roots on its left side, have been cut. Now, if the right hind leg of the frog is irritated, a response reaction will be observed only on the left side, while the right side will remain inert. When the left hind leg is irritated, no reflex action will take place (Fig. 109).

Thus, cutting the anterior roots does not prevent the passage of impulses from the skin to the spinal cord, but it stops their conduction from the spinal cord to the muscles. This means that efferent impulses can travel only through the anterior roots. The fact that no reflex action whatever takes place after the posterior roots have been cut shows that afferent impulses travel only through the posterior roots. Therefore, the anterior root is called *the motor root,* and the posterior one, *the sensory root.*

The two roots emerge from the spinal cord and join together beyond it to form one nerve. Thus, the nerves that run from the spinal cord are *mixed:* they contain nerve fibres of both types — afferent and efferent.

The reflex arc. Any reaction that takes place in response to stimulation and with the participation of the nervous system, as we already know, is called *a reflex,* or *a reflex action.* The path along which impulses, arousing reflex action, travel is called a reflex arc.

Each reflex arc (Fig. 110) consists of five parts: the first part is ***the receptive nerve endings,*** situated both in the sense organs and in all the other organs of the body — in the muscles, the intestinal canal, the lungs, and so on; the second is ***the afferent nerve;*** the third — *the central nervous system,* that is, the spinal cord and the brain; the fourth — *the efferent nerve*; the fifth and last — *the organs that react to stimulation* — the skeletal muscles, the heart, the salivary glands, etc.

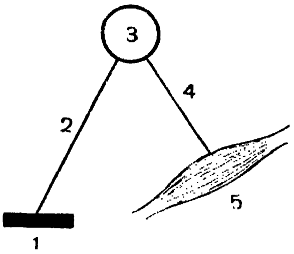


Fig. 110. Diagram of a reflex arc:

1 — organ with receptive nerve endings: 2 — afferent nerve; 3 — central nervous system; 4 — efferent nerve; 5 — organ reacting to the stimulus.

In its simplest form, the reflex arc must be composed of at least two neurons: an *afferent* and an *efferent* neuron.

An afferent neuron. The cells of afferent neurons are not located in the spinal cord, but in the posterior spinal nerve root, where they form an enlargement which is called *an intervertebral ganglion.* These neurons, unlike all the others, have two long projections. One of them carries impulses from the sensory endings in the skin, the muscles and others, to the cell body; along the other projection, impulses travel from the cell body along the other projection to the spinal cord. In the spinal cord this projection branches out: one branch runs along the white matter to the lower parts of the spinal cord, while the other is directed upward. Both of these branches give off short little side branches, which enter the gray matter and terminate there.

An efferent neuron. An efferent neuron has one long projection (an axon) and several short ones (dendrites). The cell bodies are in the anterior protuberances, or, as they are usually called, *the anterior horns* of the gray matter. From there the long projection passes through the anterior spinal nerve root, then along the spinal nerve, and enters a working organ — a muscle, for instance.

The little branches of the long projection of the afferent neuron, leading close up to the anterior horns of the gray matter, come in contact with the dendrites of the efferent neuron. Excitation may be transmitted only from the axon to the dendrites. No excitation is transmitted in the opposite direction — from the dendrites to the axon. Thanks to this, we have the unilateral conduction of excitation in the central nervous system.

The knee-jerk. The knee-jerk may serve as an example of a reflex, the arc of which consists of two neurons. If a person seated on a chair is told to cross his legs, and is then given a sharp blow with the side of the hand, or, still better, with a small hammer, on the tendon just below the knee-cap, the leg will give a violent jerk. The tendons which receive the blow sag and pull with them the muscle which straightens out the leg at the knee. The muscle is stretched, which gives rise to irritation of the receptive nerve endings of that very same muscle. In this way a stream of impulses is set up, which travel along the afferent neurons to the spinal cord, and from there, along the efferent neurons, return to the same muscle, arousing a response in it — it is shortened (see coloured plate VI).

The internuncial neurons. Reflex arcs that consist of two neurons occur very rarely. Most reflex arcs consist of three, four and of even more neurons. Diagrams of reflexes consisting of two and three neurons are given in coloured plate VI. As shown there, the little branches of the projection of the afferent neuron lead up to *the posterior,* and not only to the anterior horns of the gray matter. Here are located the bodies of *the internuncial neurons,* which transmit impulses from the afferent to the efferent neurons.

The long projections of the internuncial neurons extend to every part of the spinal cord, as well as to the brain. Thus, by travelling from one internuncial neuron to another, excitation is transmitted to all parts of the central nervous system.

Problem. Make a drawing of two neurons, showing the axon of one neuron directed to the dendrites of the second neuron, and the axon of the second neuron directed to a muscle. Add all the necessary explanations to your drawing. Show, by means of arrows, the direction that excitation can take.

61. Reflexes of the spinal cord

Reflexes in a decapitated frog. Reflexes that take place with the participation of the spinal cord may be best studied in a frog whose head has been cut off, but whose spinal cord has been left intact. In order to observe the reflexes, the frog is suspended from the hook of a support.

If the leg of the decapitated frog is pinched with a pair of pincers, the leg is jerked back. Two of the frog's legs, or three and even all four of them, may be brought into motion, depending upon the force with which they are pinched. This experiment shows that excitation may spread, or *irradiate,* to the various parts of the spinal cord.

The excitability of the nervous system. The spreading of excitation, in other words, the transmission of excitation from one neuron to another, depends upon the degree of excitability of the nerve cells. A careful study of the changes in the excitability of nerve cells may be made by watching the action of certain poisons on a decapitated frog. Thus, alcohol at first increases the excitability for a very short period of time, but then diminishes it greatly. Strychnine increases the excitability to such an extent that even the slightest contact with this poison will bring about convulsive contractions of all the muscles of the animal's body.

The significance of afferent impulses. In the central nervous system, streams of impulses are continuously travelling from all parts of the body along the afferent neurons. Some of them arouse response reactions, but the overwhelming majority of them are too weak to bring about a reflex. Nevertheless, the organism is not entirely indifferent to these impulses. They increase the excitability of the cells of the central nervous system.

We may take such weak stimuli (for example, an electric current) which, taken separately, do not bring about reflex action in a decapitated frog. If these stimuli are again applied with a definite frequency, several times one after another, a reflex action will occur, because each stimulus increases the excitability of the cells.

In certain diseases, a person may lose the power of sensation. In one case, the patient lost all power of sensation in his skin; he was blind of one eye and deaf in one ear. The moment his unaffected ear was stopped with cotton wool and his unaffected eye bandaged up, the excitability of his nervous system was so greatly diminished that he immediately became motionless and fell asleep. This state disappeared when the bandage was removed from his eye and the cotton wool from his ear.

The example just given shows the vast importance of the afferent impulses for the activity of the whole central nervous system, even in such cases when they do not call forth a reflex action.

The inhibition of reflexes. If the tip of the hind leg of a decapitated frog is immersed in a weak solution of sulphuric acid, the leg is almost immediately jerked back (usually in one to three seconds). If the foreleg is squeezed with a clamp when the hind leg is immersed in the acid, the reaction will take place considerably later, and sometimes will not occur at all.

In this case, two streams of impulses enter the central nervous system simultaneously: from the foreleg irritated by the clamp, and from the hind leg immersed in the acid. The stream of impulses from the foreleg does not increase the excitability of the nerve cells which take part in the reflex action of the hind leg, but, just on the contrary, it suppresses — inhibits — the activity of the nerve cells. Such inhibition delays the reflex.

Inhibition in the central nervous system was first made a deep study of by the great Russian physiologist, Setchenov. At the present time, it is an established fact that each nerve cell can be brought to *a state of excitation*, as well as to *a state of inhibition*. A state of inhibition must not be considered as a state of rest or of inactivity. It is actually a state of activity of the cells, but the activity is of a type that will not allow an impulse to pass through the cells (Fig. 111). Travelling reflexes, whose path is obstructed by a zone of inhibition, become weakened or disappear altogether during the whole time the inhibition lasts. Both states of the nerve cells — excitation and inhibition — are equally important to ensure the normal activity of the nervous system.

Coordination of reflexes. When a decapitated frog jerks back its legs in response to an irritation, a whole group of flexors are contracted. This is due to the fact that the centres of the flexors in the spinal cord are excited, that is, those groups of nerve cells are excited whose projections are connected with the flexors. The tone of the extensors is lowered simultaneously, and they relax, thus enabling the frog to bend its leg. The extensors relax, because the nerve cells connected with these muscles, — in other words, the nerve centres of the muscles are brought to a state of inhibition.

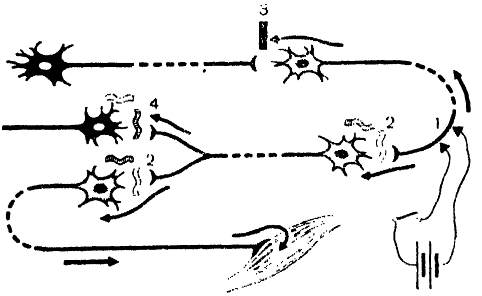


Fig. 111. Diagram of the conduction of an impulse from one neuron to another:

1 — point of stimulation of the nerve fibre by an electric current; *2* — transmission of excitation from the axon to the dendrite; *3* — excitation cannot pass from the dendrite to the axon; *4* — inhibition that is formed prevents the passage of excitation.

The reactions of a frog, kept for some time in the cold (at a temperature of 0°, for example), are greatly retarded. When the frog, subjected to such conditions, bends its leg in response to stimulation, the leg remains bent for rather a long time, and begins to straighten out slowly only after several seconds. If the right leg is pinched with a pair of pincers immediately after the stimulation of the left leg, the left leg will straighten out at the same time that the right one will bend.

In the experiment showing the retarded reactions of a frog that has been exposed to the cold, we may readily observe the integrated action of the nerve centres: the excitation of the centres of the flexors of the right leg brings about the inhibition of the centres of those muscles of the left leg which were in a state of excitation; as a result, the left leg straightens out at once. When any kind of a motion is made, some muscles contract and others relax, all of which depends upon the appearance of zones of excitation and of inhibition in the corresponding sections of the central nervous system. Such interactivity of the centres was first determined by the outstanding Russian physiologist — N. V. Vvedensky.

Zones of excitation and of inhibition do not remain constant. They are always shifting from one place to another, from one part of the brain to another, thus making the proper coordination of movements possible.

The complex movements of a decapitated frog. If a piece of paper soaked in acid is applied to the skin of a decapitated frog, the frog will throw it off with a precise movement of its leg. The frog will bring into motion its right or its left leg, depending upon the point of the body to which the acid is applied. Thus, if the piece of paper is applied to the right side of the body, the frog will remove it with its right hind leg.

This experiment may be performed in a somewhat different way, — by tying the right leg tightly so that it cannot be moved, as shown in the figure (Fig. 112). Now, if the right side is irritated, the muscles of the right leg that is tied will contract first, and then the other leg (the left) will begin to move toward the piece of paper, and will throw it off.

This interesting experiment shows that movements may be coordinated very exactly by the spinal cord alone. With the addition of the brain, reflex actions become still more complex and infinite in variety.

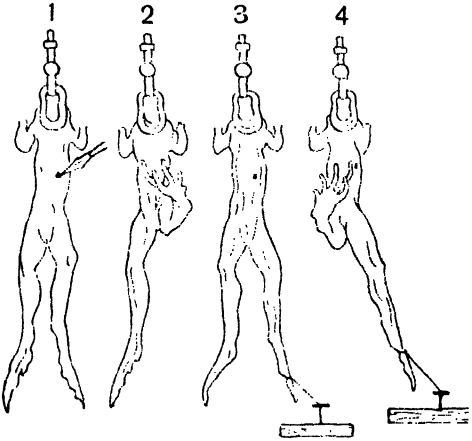


Fig. 112. Experiment with a decapitated frog irritated by an acid:

1 and *2* — the frog rubs off, with its right leg, the acid from the right side of its back; *3* and *4* — the right leg is tied; the frog rubs off the acid from the same place with its left leg.

The role of the spinal cord. In the organism taken as a whole, with its nervous system unimpaired, the chief role of the spinal cord is that of *a conductor of impulses* that travel both from the organs of the body to the brain, and back again from the brain to the organs. *The reflex actions* of the spinal cord depend upon the upper divisions of the central nervous system; in the lower vertebrates, this dependence is expressed more weakly than in mammals. It is the participation of the brain, and especially of the cortex of the cerebral hemispheres, that accounts for the striking variety of reactions, which so greatly differentiates the reflex actions of an unimpaired organism from the reflexes of an animal having only a spinal cord (the brain having been removed). In the human being, even such simple reactions of the spinal cord as the knee-jerk cannot take place without the absolute participation of the brain.

Questions. 1. In some diseases, only the conduction of excitation from the spinal cord to the brain is destroyed, while the conduction of excitation in the opposite direction (from the brain to the spinal cord) proceeds normally. Will there be a knee-jerk under such conditions? Will the leg be sensitive to a pin-prick? Are voluntary movements of the leg possible? Explain why some of the questions require positive answers, and some — negative answers.

2. How must these same questions be answered, if: a) the pathway along which excitation is conducted from the brain to the spinal cord is injured? b) the posterior spinal nerve roots of the spinal cord are injured? c) the anterior spinal nerve roots are injured? Give the reasons for each of your answers.

3. Why does the secretion of gastric juices cease in a dog the moment a cat is brought near it? Give other examples of similar reactions. Explain each of them.

Problems. 1. Make a drawing of a cross-section of the spinal cord, with a diagram of the simplest type of a reflex arc composed of two neurons (the arc should originate in a muscle or in its tendon, and should terminate in the same muscle). Give a detailed explanation in your drawing. Show the pathway of the excitation by means of arrows.

2. Make a diagram of a reflex arc composed of three neurons, and originating in the skin. Give a detailed explanation in the diagram. Show the pathway of the excitation by means of arrows.

3. Try the knee-jerk on yourself or on your school-mate. Explain why there is a contraction of the extensors and why the leg jumps.

§ 62. The structure of the brain

The cerebral vesicles. The central nervous system in the embryo of all vertebrates begins as a tube with an enlargement at its anterior end (Fig. 113). The transverse bands on each of the three parts of this end give them the appearance of three swellings, which are called *the anterior, the mid-* and *the posterior cerebral vesicles;* each of these vesicles represents the beginning of definite parts of the brain.

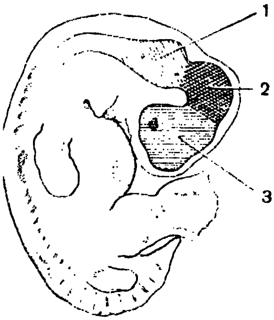


Fig. 113. Anterior end of the cerebral tube in the human embryo:

1 — posterior; 2 — mid-; 3 — anterior cerebral vesicles.

The hind-brain. That part of the brain of a human being which is a direct continuation of the spinal cord is called *the medulla oblongata.* In front of the medulla there is a large cylinder-like elevation, running crosswise, which is usually referred to as a bridge, — *the pons.* Behind the medulla there is *the cerebellum*, divided into two hemispheres, one on each side. All of these parts develop out of the posterior cerebral vesicle, and compose the hind-brain.

The mid-brain. The continuation of the hind-brain is the mid-brain, which develops out of the mid-cerebral vesicle, and composes a very small part of the brain in man.

The mid-brain consists of *the cerebral peduncles* (two very thick bundles of fibres which penetrate deep into the right and left hemispheres) and the four eminences *(corpora quadrigemina),* situated behind the cerebral peduncles. If the cerebral hemispheres are lifted up, then, between the hemispheres and the cerebellum may

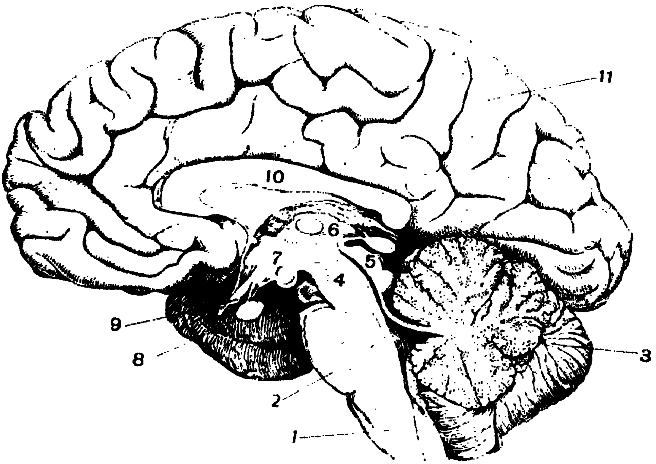


Fig. 114. Longitudinal section of the human brain:

1 — medulla oblongata; 2 — pons; *3* — cerebellum; 4 — mid-brain; *5* — two eminences of the corpora quadrigemina (posterior part of the mid-brain); *6* — thalamus; *7* — hypothalamic region; *8* — pituitary gland; *9* — optic nerve; *10* — corpus callosum; *11* — cortex of the cerebral hemispheres.

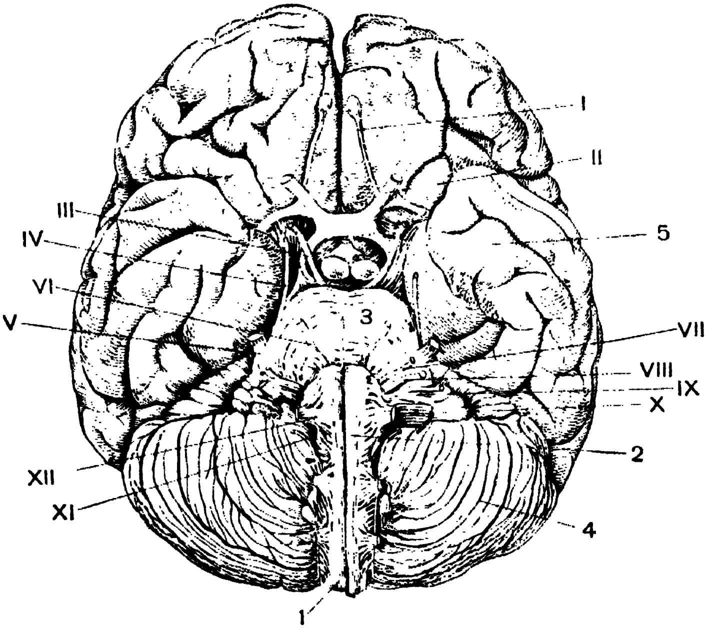


Fig. 115. Interior surface of the human brain:

1 — spinal cord passing over into the medulla oblongata (*2*); *3* — pons; *4* — cerebellum; *5* — cerebral cortex; *I* — *XII* — twelve pairs of cranial nerves; among these are: olfactory nerve (*I*), optic nerve (*II*), facial nerve (*VII*), auditory nerve (*VIII*), vagus nerve (*X*).

be seen four eminences; these are the corpora quadrigemina (in figure 114 only two of these eminences are seen).

The fore-brain. The remaining part of the brain is developed out of the anterior cerebral vesicle, and is called the fore-brain. *The inter-brain* (diencephalon) is developed out of the posterior part of the anterior vesicle. The inter-brain consists of two large aggregations of gray matter — *the thalamus*, and, situated below the thalamus — *the hypothalamic region.*

Out of the anterior part of the same vesicle are developed *the cerebral hemispheres*, the surface of which consists of gray matter and is called *the cerebral cortex*. There are also aggregations of gray matter *(the subcortical centres)* deep within the cerebral hemispheres.

The nerves of the brain. Twelve pairs of *cranial nerves* originate in the lower surface of the brain (Fig. 115). Some of them connect the brain with the sense organs (the auditory, optic and olfactory organs); others contain fibres which lead to the muscles and to the skin of the scalp, to the mucous membrane of the mouth and nose cavities, and to the salivary glands.

One of the nerves, called the wandering nerve, or *the vagus nerve*, breaks up into branches that lead to the organs of the thoracic and abdominal cavities; the name — wandering nerve — was given to it because it, so to say, wanders about in the body.

63. The brains of different vertebrates

The similarity in structure of the brains of different vertebrates. If we compare the brains of various vertebrates, including that of the human being, it is not difficult to note that there are many similarities in their structure. In all vertebrates, the brain is developed out of the three initial cerebral vesicles. All vertebrates possess the chief divisions of the brain (the medulla oblongata, cerebellum, mid-brain, inter-brain or diencephalon, the hemispheres). However, together with these points of similarity, there are also outstanding differences.

The weight of the brain. The weight of the brain is an important factor proving that the brain, in the various classes of vertebrates, did not undergo the same development.

The brain of most fish weighs less than their spinal cord; in amphibians and reptiles, the brain is of about the same weight as the spinal cord; in mammals, it weighs considerably more than the spinal cord; in dogs, its weight is five times greater than that of the spinal cord, and in man-like apes it is 15 times greater. However, in no animal has the brain reached such a high state of development as in man, whose brain composes about 98% of the weight of the whole central nervous system.

The brain of fish. The hind-brain and the mid-brain of fish are greatly developed (Fig. 116). The fore-brain is very poorly developed and is evidently only concerned with the sense of smell.

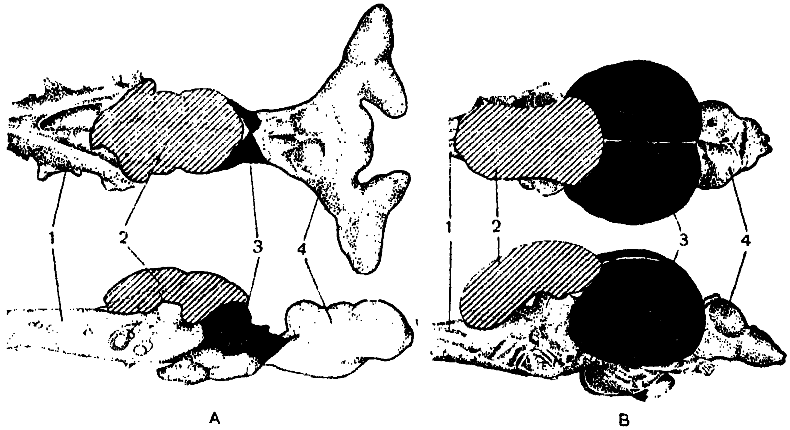


Fig. 116. Top and side views of the brain of fish;

A — cartilaginous fish (shark); *B* — osseous fish (salmon). *1* — medulla oblongata; *2* — cerebellum; *3* — mid-brain; *4* — fore-brain.

If the whole fore-brain of a fish is cut out, the fish will continue to behave in a normal manner: it will swim up to things thrown into the aquarium and will distinguish between what is edible and what is inedible; it will quickly swim away from danger. If the mid-brain is destroyed, a great change takes place in its behaviour; moreover, coordination in the execution of its movements is partially destroyed.

The brain of amphibians. In amphibians (for example, the frog), the fore-brain is somewhat more developed than in fish (Fig. 117) and its removal brings about a number of disorders in the animal's normal behaviour; however, the disorders produced are not lasting ones, and in one or two weeks after the operation they disappear by themselves.

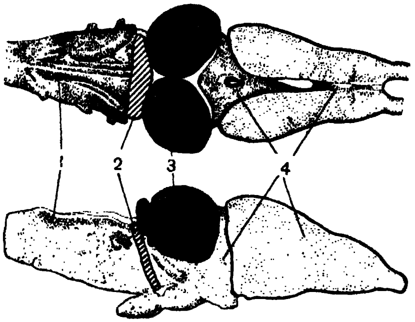


Fig. 117. Brain of amphibians (frog). The denotations are the same as those in figure 116.

The brain of reptiles and birds. In reptiles (Fig. 118, *A*) some parts of the fore-brain, namely, the inter-brain and the subcortical centres, are rather well developed. The cortex of the hemispheres contains few nerve cells. When the fore-brain is removed, very noticeable changes are produced in the behaviour of the animal, although coordinated movement is not destroyed: the animal becomes very inactive, does not look for or seize upon food, and shows no fear of a person.

The considerable size of the cerebral hemispheres in birds (Fig. 118, *B*) is explained by the exceptionally powerful development of their subcortical centres; the cortex of the hemispheres is almost as little developed as in reptiles. If the cortex alone is carefully removed, very little change is observed in the behaviour of the animal. If both hemispheres are completely removed (the cortex and subcortical centres), the changes produced will be the same as those caused by the removal of the fore-brain in reptiles.

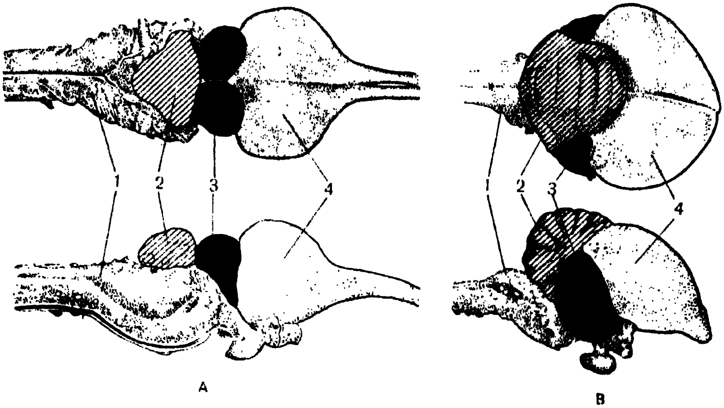


Fig. 118. Brain of reptiles and birds:

A — crocodile; *B* — pigeon. The denotations are the same as those in figure 116.

The brain of mammals. Their highly developed fore-brains is a feature that differentiates mammals from other vertebrates (Fig. 119). The mid-brain of mammals is very poorly developed.

If the whole fore-brain is removed, the disturbance produced is so great that the animal loses the power of motion; it becomes absolutely helpless, and soon dies. Even if only the cortex of the cerebral hemispheres of animals is removed, the result is great disorder in behaviour.

A dog with the cortex of the hemispheres removed does not move toward food nor eat it unless its muzzle is forcibly thrust into the bowl of food. It does not recognize its master; it snaps and snarls if anyone touches it; there is no response of any kind either to kind words and patting or to harsh words and threatening motions; it does not react to the presence of a cat; it becomes very inactive, often stumbles over obstacles put in its way and stands for a long time in front of them without moving.

If the cerebral cortex of a monkey (Fig. 120) is completely removed, the disturbances created are still more profound. Besides such disorders in behaviour as are observed in dogs, monkeys lose the ability to make voluntary movements, and sleep almost all the time.

The evolution of the brain. In the process of the historical development of vertebrates, complexity in behaviour is closely connected with the development of the brain, and especially of its anterior division.

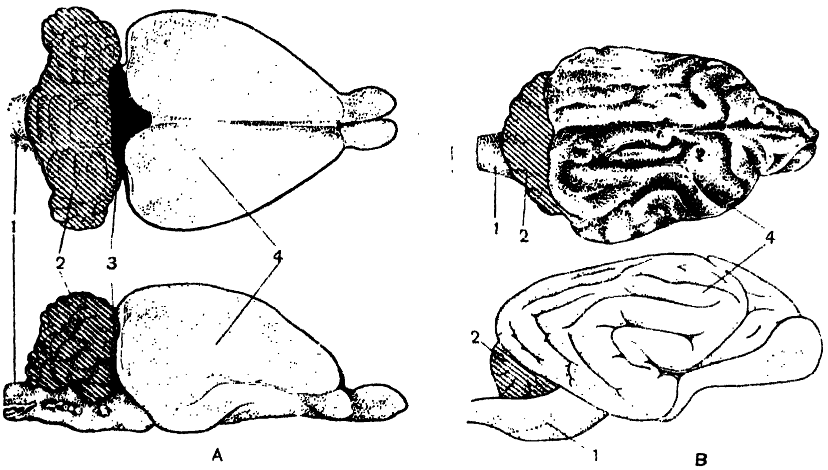


Fig. 119. Brain of mammals:

A — rabbit; *B* — dog. The denotations are the same as those in figure 116.

In the lower vertebrates, the hind- and mid-brains are greatly developed, but the small fore-brain is of no real significance in regulating the activity of the organism. Higher, more complex phenomena of nervous activity, connected with the fore-brain, first appeared in reptiles.

The fore-brain became still more developed in mammals. A new section of the brain appeared — the cortex of the cerebral hemispheres — which is practically wanting in other animals. Even in monotremata (the duckbill, the anteater, for example) and in marsupials, the cerebral cortex became greatly enlarged at the expense of the olfactory lobe of the fore-brain; but, in the higher animals, due to the still greater development of the cortex, the cerebral hemispheres increased in size in all their parts to such an extent that they cover up the other parts of the brain; fissures and convolutions appeared in the cortex, increasing its area considerably.

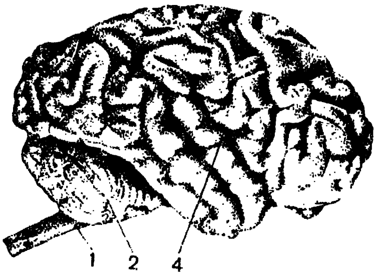


Fig. 120. Brain of a monkey. The denotations are the same as those in figure 116.

In mammals, it is with the cortex of the cerebral hemispheres that all the higher manifestations of nervous activity are connected. Therefore, the removal of the cortex of these animals is the cause of very violent disturbances and changes in their behaviour.

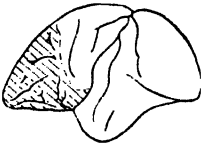


Fig. 121. Fore-brain of a monkey. Part of the frontal lobe in front of the motor centres is shaded.

In monkeys, it is not only the higher forms of nervous activity, but also all the voluntary movements, that are controlled by the cerebral cortex; therefore, with the removal of the cortex, the ability to make any voluntary movements is destroyed.

The brain of a human being. The extraordinarily great development of the cortex of the cerebral hemispheres, and especially of the anterior (frontal) lobe, fundamentally differentiates the brain of man from that of the lower animals (Fig. 121 and 122). Due to the vast numbers of fissures, some of which are very deep, the entire surface of the hemispheres is covered with numerous folds, or convolutions. If all the folds were spread out flat, the human cortex would occupy an area almost equal to 2000 *sq. cm.*, which is all the more striking when we consider that the surface of the cortex of such a large animal as the horse is only 350 *sq. cm.*

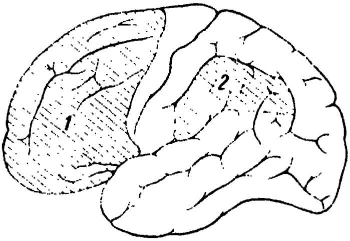


Fig. 122. Fore-brain of a human being. Part of the frontal lobe in front of the motor centres (*1*) and the lower parietal region (*2*) is shaded.

The structure of the human cortex as seen under the microscope is very much more complex than that of any animal. It is considered that there are about 14 milliard nerve cells in the human cortex.

In the human being, life is impossible without the cortex of the cerebral hemispheres. Even small injuries of the cortex may have very serious results.

64. The functions of the hind- and mid-brains

The medulla oblongata. Most of the cranial nerves are connected with the medulla oblongata and with the pons situated in front of it. Here come afferent impulses from the organ of hearing, the skin of the scalp, the mucous membrane of the mouth cavity. From the medulla oblongata, efferent impulses travel to all the muscles of the head and to the salivary glands. The medulla oblongata is connected with the organs of circulation, digestion and respiration by means of the afferent and efferent fibres of the vagus nerve.

Reflex arcs, connected with functions of the most vital importance, pass through the medulla oblongata and also through the pons; the following *centres* are located here: *the respiratory* and *cardio-vascular centres, the centres of the facial muscles that produce the "expressions" of the face, the centres of masticating, swallowing, vomiting, sneezing, coughing, salivary secretion*, and many others.

If the whole fore-brain and the whole mid-brain of a mammal are removed, the respiratory movements and the work of the circulatory and digestive organs go on quite normally. But, on the other hand, if the separate centres of the pons and of the medulla oblongata are injured, the work of these organs is seriously affected.

The respiratory centre of the medulla oblongata integrates and coordinates the work of the separate respiratory muscles, the centres of which are situated in the anterior horns of the gray matter of the spinal cord. If the spinal cord of a mammal is cut,— in other words, if the spinal cord is separated from the medulla oblongata, respiration immediately ceases, because the connection between the respiratory centre and the spinal centres of the different respiratory muscles is destroyed. This experiment shows that respiratory movements are regulated by the respiratory centre through the medium of the lower centres of the spinal cord.

In the same way, the medulla oblongata also integrates and coordinates the activity of several other lower centres of the spinal cord.

Distribution of muscle tone. To preserve the equilibrium of the body and to keep it in a correct position requires the highly intricate and integrated activity of all the skeletal muscles. The tone, that is, the tension, of each separate muscle must be in perfect harmony with the tone of the other muscles. If the tone of the extensors of the lower extremities is diminished, but the tone of the flexors remains unchanged, there is an over-balance on the side of the flexors; as a result, the legs double up and the person is unable to stand.

Sometimes, in cases of injury to the facial nerve, the tone of the facial muscles, which produce expressions of feelings, is lowered. If the injury affects only the right nerve, the muscle tone of the right side of the face is weakened, whereas the muscle tone of the left side remains normal. In such a case, the whole face is twisted to the left side. Cross-eyes, that sometimes occur in people, may be the result of the lowered tone of one of the muscles of the eye-ball.

The maintenance of muscle tone, and, consequently, the preservation of the body in a normal position, is provided for by a stream of afferent impulses, among which the impulses coming from the muscles and joints are of special importance. These are perpetual signals as to the position of the body in space, and produce corresponding reflex actions that serve to maintain the correct position of the body.

The proper distribution of tone is destroyed if the mid-brain is injured.

The otolithic mechanism and the semi-circular canals. The otolithic mechanism and the semi-circular canals are situated within the temporal bone, close to the organ of hearing (see coloured plate VIII).

The otolithic mechanism consists of two little sacs, on the inner surface of which there are sensory cells supplied with little hairs. Little lumps of crystals of lime — otoliths, are suspended from these hairs. Any change in the position of the head causes the otoliths to exert a pull on the little hairs, and thus the endings of the nerve fibres connected with the hairs are excited. Impulses coming from the otolithic mechanism produce reflex actions which help to maintain a correct position of the body.

Three semi-circular canals, originating in one of the sacs of the otolithic mechanism, extend in three respective perpendicular planes. Any movement of the head agitates the fluid in the canals, and thus pressure is exerted on the sensory cells connected with the endings of the nerve fibres. The impulses aroused by this produce reflex actions that maintain the equilibrium of the body when in motion.

Orienting, or focusing, reflexes. Any unexpected sound or light stimulus brings about an orienting reflex in a person. He is all attention and immediately turns his head in the direction of the sound or light that irritated him.

In mammals, orienting or focusing reflexes to sound and light occur even when the whole fore-brain is removed, if only the mid-brain is left intact. The centres of these complex reflexes, so important because of their protective nature, are found in the aggregations of gray matter that form the corpora quadrigemina.

The cerebellum. The surface of the cerebellum, which consists of gray matter, presents a corrugated appearance because of the great number of fissures. Impulses from all the muscles of the body, and also from the fore-brain, and especially from the cerebral cortex, are directed to the cerebellum through the internuncial neurons of the spinal cord and of the medulla oblongata.

Like all the other divisions of the brain, the cerebellum takes part in the coordination of movements. If the cerebellum is injured, the result is a lack of orderliness and exactness in movements. When the cerebellum is removed from a dog, the dog's gait becomes unsteady; all its movements are clumsy and angular and are made with great difficulty; it is unable to approach the point of destination in a straight line, because all preciseness in the contractions of the separate muscles has disappeared (Fig. 123). A dog with its cerebellum removed is unable to seize at once a piece of meat lying on the floor: it drops its head many times in vain attempts to grasp at the food, striking the ground hard with its muzzle, either to one or the other side of the food; after many such vain attempts, the dog at last snatches up the meat as if it has come upon it by chance.

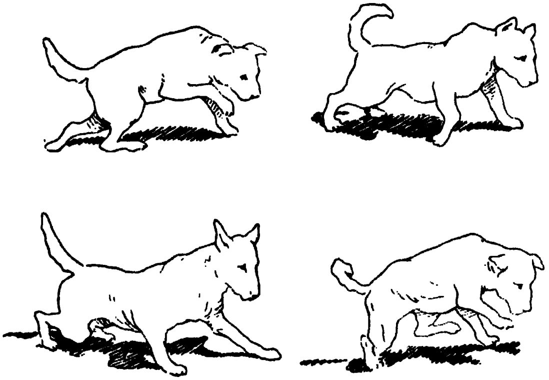


Fig. 123. Movements of a dog whose cerebellum has been removed.

In people, the functioning of the cerebellum is impaired in cases of certain diseases, and also in cases of drunkenness. Impaired functioning of the cerebellum results in the lack of ability of a person, also, to coordinate his movements.

The chief role of the cerebellum is to add precision to the force, duration and order of succession of the contractions of the separate muscles; in other words, to put the finishing touches to the movements and to polish them up.

65. The functions of the fore-brain

The thalamus and the subcortical centres. Impulses coming to the central nervous system from all parts of the body reach the anterior sections of the brain, and especially the cerebral cortex, through the internuncial neurons. However, before getting to the cortex, all the afferent impulses must absolutely pass through the thalamus of the inter-brain. The thalamus consists of gray matter and, consequently, is an aggregation of nerve cells. From the cells of the thalamus, the nerve fibres are directed to the cerebral cortex and also to the subcortical motor centres. (Fig. 124).

The subcortical centres take part in the execution of complex movements. If the subcortical centres become diseased, the so-called auxiliary movements are disordered, as, for example: the swinging of the arms when walking, the changing expressions of the face when talking, etc. The face of the patient becomes set, without any motion, like a mask; or, vice versa, as a result of the excessive contractions of the muscles that produce the varying expressions of the face, one grimace follows another on the face.

Besides this, the subcortical centres help to regulate the rhythmically repeated movements (of walking, for instance), and also those complex reflex movements, connected with the manifestations of the instincts.

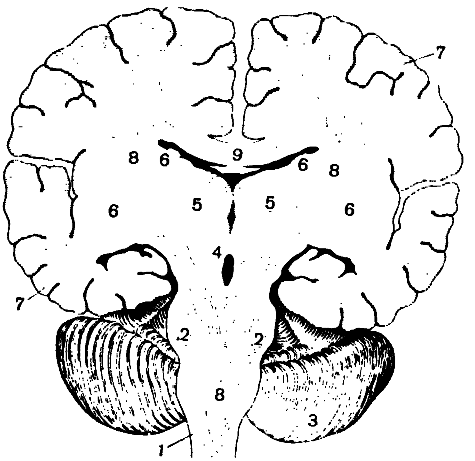


Fig. 124. Cross-section of the brain:

1 — medulla oblongata; *2* — pons; *3* — cerebellum; *4* — mid-brain; *5* — thalamus; *6* — corpus striatum; *7* — cerebral cortex; *8* — pathway of the efferent fibres from the cerebral cortex to the spinal cord (the crossing of the fibres is seen at the bottom); *9* — fibres connecting the right and left cerebral hemispheres.

The hypothalamic region. The masses of gray matter located under the thalamus are of great importance for the activity of the whole organism. The centres of the hypothalamic region regulate the processes of metabolism and the activity of the internal organs. The projections of the nerve cells unite this region with the cortex and with the subcortical centres, as a result of which a connection is set up between the motor reactions of the organism, the work of the internal organs, and the processes of metabolism.

The cerebral cortex. The cortex of the cerebral hemispheres is an organ of higher nervous activity. It provides for the reactions of the organism to the ever changing conditions of the environment. Impulses from the sense organs, the muscles, the tendons and the internal organs keep on flowing to the various sections of the cerebral cortex. The nerve pathways leading to the cortex cross each other; therefore, impulses from the left half of the body enter the right hemisphere, and those from the right half enter the left hemisphere.

The cerebral cortex is divided up into *lobes — the frontal, parietal, temporal* and *occipital lobes.* Two large fissures are seen in figure 125, *A.* One of them (the *transverse* fissure) separates the temporal lobe from the frontal and parietal lobes; the other (the *central* fissure) serves as a border line between the frontal and parietal lobes.

The various parts of the cerebral cortex differ as to their structure and functions. *The visual area,* the activity of which produces visual sensations, is localized in the occipital lobe. *The auditory area* is localized in the temporal lobe. *The centres associated with the sensitivity of the skin* lie behind the central fissure, that is, in the anterior part of the parietal lobe. *The motor area* (Fig. 126) is situated in front of the central fissure, in the posterior part of the frontal lobe.

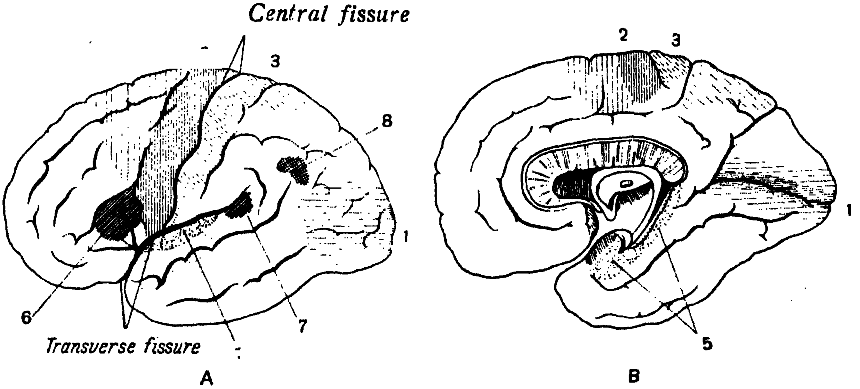


Fig. 125. Distribution of the centres in the cortex of the cerebral hemispheres on the outer (*A*) and inner (*B*) surfaces of the hemispheres:

1 — centre for vision; *2* — motor centre; *3* — centre for tactile sensitivity; *4* — centre for hearing; *5* — centres for taste and smell; *6* — motor centre for speech; *7* — auditory centre for speech; *8* — visual centre for speech.

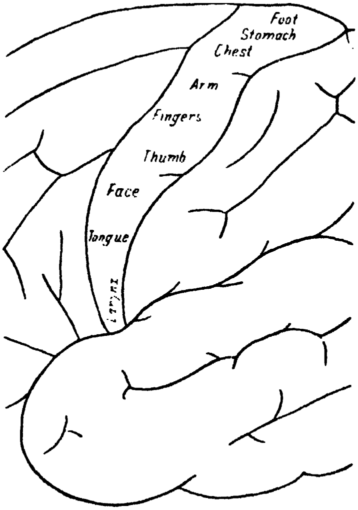


Fig. 126. Motor area of the cortex of the cerebral hemispheres.

In certain disorders of the brain, the separate parts of the cerebral cortex become affected and, as a result, disturbances arise in their corresponding functions. Thus, for example, a hemorrhage in the motor area brings about paralysis of the opposite half of the body; the pressure of a tumour in the visual area may cause blindness.

The role of the separate sections of the cerebral cortex has been studied time and again during operations, when the skull is cut open and the surface of the brain exposed. In such operations the patient is not narcotized. In order that he should feel no pain when the skin is cut and the skull opened up, special anesthetics, which act only on the place they come in contact with, are injected under the skin. There is no pain even when the brain itself is operated on. The patient is fully conscious all the time; the surgeon keeps on talking with him during the operation, inquiring how he feels, and at the same time watching whether some vitally important centre is not accidently touched. If the visual area of the cerebral cortex is irritated with an electric current during the operation, the patient has the sensation of a sudden flash of light passing before his eyes; if the motor area is irritated, the patient makes some movement or other.

Irritation of a definite section of the motor area of the cortex always produces one and the same kind of movement. This means that each group of muscles has its own localized centre in the cortex.

As investigations made by Mislavsky, Bekhterev, Bykov and other scientists have shown, there are areas in the cerebral cortex, which, when irritated, influence the work of *the internal organs.* There is a close and interrelated connection between the cortex of the cerebral hemispheres and all the lower divisions of the brain: afferent impulses from the lower divisions of the brain enter the cortex, while efferent impulses from the cortex travel to the lower divisions. Thus, the work of all the organs of the body is controlled by the cerebral cortex, and this control is achieved by means of the other divisions of the central nervous system.

The areas connected with the sense organs and the motor centre occupy a considerably smaller part of the cortex in the human being than in animals. But, then, about 30% of the whole surface area of the human cortex is taken up by the frontal lobe, and about 9% by the lower parietal area (Fig. 122). Both of these areas of the cerebral cortex differ widely, both in size and in structure, from the corresponding areas in animals, and thus they evidently play a very great role in the higher nervous activity of a human being.

Articulate human speech is connected with special areas of the brain, which are lacking in animals. The so-called centres for speech are located in the cerebral cortex. The localization of *the motor, auditory* and *visual centres for speech* is shown in figure 125. Any injuries to these areas will bring about the loss of the ability to speak, to hear spoken speech and to understand written speech. However, it is necessary to add that the functions of speech are not restricted only to these areas of the cerebral cortex, but that they are also connected with its other divisions.

66. The vegetative nervous system

The innervation of the internal organs. That part of the peripheral nervous system which connects the brain with the internal organs is called the vegetative[1] nervous system. There are two divisions of the vegetative nervous system: the *sympathetic* and *parasympathetic* systems.[1] The internal organs have a *double innervation:* each of them receives impulses from the central nervous system both through the sympathetic and parasympathetic divisions of the vegetative nervous system (see coloured plate VII).

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[1] Vegetative comes from the Latin word "vegetativus" — plant. In the first half of the 19th century the functions of the organism were divided into those of animals (movements) and those of plants (nutrition, respiration, elimination and others). The nerves leading to the "organs of plant life" were named vegetative.

The connection between the vegetative nervous system and the brain. Vegetative nerves issue only from certain divisions of the brain.

The nerves of the sympathetic system have their origin in the spinal cord, on a level with the thoracic and upper lumbar vertebrae. The parasympathetic nerves issue from separate sections of the medulla oblongata and of the mid-brain, and also from the lower part of the spinal cord.

The vegetative nervous system has a two-fold connection with the brain: the nerves of the vegetative nervous system are composed of both afferent and efferent fibres.

Those sections of the brain from which impulses travel to the vegetative nervous system are usually called *vegetative centres.* Thus, for example, the cardio-vascular, food and other centres in the medulla oblongata are vegetative centres. The centres of the hypothalamic region, which are connected with the processes of metabolism and with the activity of the internal organs, are often called *the higher vegetative centres.* However, all these centres are under the control of the cortex of the cerebral hemispheres and are closely connected with all the other divisions of the brain. This, for example, explains the connection between the work of the heart and the activity of the muscles.

The sympathetic system. Bundles of sympathetic fibres, issuing through the anterior roots of the spinal cord, extend to the two *sympathetic trunks* situated on either side of the spinal column; on the sympathetic trunks there are a number of enlargements or *ganglia,* formed by aggregations of sympathetic nerve cells. Numerous bundles of fibres pass from the sympathetic trunk to all the organs of the body. Aggregations of nerve cells are also found along the pathways of these bundles of fibres, especially on the walls of the large arteries and in the internal organs themselves.

A very large aggregation of nerve cells lies on the aorta in the abdominal cavity. This aggregation is called *the solar plexus.* Even a slight irritation of the solar plexus causes a reflex change in the activity of the heart and of other internal organs; a violent irritation may bring about a complete cessation of the heart contractions. This explains the loss of consciousness that sometimes follows a strong blow on the stomach. From the solar plexus, the sympathetic fibres are directed to the stomach, the intestines, the liver, the kidneys and to all the other organs of the abdominal cavity.

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[1] Sympathetic comes from the Greek word "sympathes". This term originated long ago, when it was thought that there was a connection or "sympathy" between the internal organs, brought about with the help of special nerves. Parasympathetic means — at the side of the sympathetic — from the Greek word "para", meaning — near, at the side of, alongside of.

The sympathetic pathway from the spinal cord to any organ consists not of one neuron, but of *two;* the body of one of these is found in the spinal cord (in the lateral protuberances of the gray matter), and the body of the other is in one of the sympathetic ganglia.

The sympathetic fibres, issuing from the spinal cord, lead to the nerve cells of the sympathetic ganglia and terminate there; these fibres have a thinner sheath. The long projections of the cells of the sympathetic ganglia, leading directly to the organs of the body, have no white sheath at all; they are, therefore, of a grayish colour, and are very much finer than the fibres of the motor nerves.

The rate of conduction of excitation in the sympathetic fibres is usually not over one or two metres per second, whereas the rate of conduction in the motor nerves is about 100 metres a second.

The sympathetic innervation of the skeletal muscles. Some fibres are directed back from the cells of the sympathetic trunk to the anterior roots of the spinal cord and, together with the efferent (motor) fibres, extend to all the skeletal muscles. At one time it was considered that these fibres exerted influence only on the blood vessels. However, the Soviet scientist, Orbeli, determined the fact that there was sympathetic innervation of the muscle fibres. Although the impulses which travel along the sympathetic fibres do not cause contractions of the muscles, they, nevertheless, have a tremendous influence on the working capacity of the muscles.

This may be shown by means of an experiment. Every muscle may be brought to a state of fatigue by compelling it, through the stimulation of the motor nerve, to keep on contracting rhythmically for a long time. But if, in addition to the rhythmic stimulation of the motor nerve, the sympathetic fibres are stimulated, the contractions of the fatigued muscle gain in force at once (Fig. 127).

The parasympathetic system. The parasympathetic system innervates the internal organs mainly.

Most of the internal organs are supplied with nerve fibres by *the vagus nerve.* On issuing from the medulla oblongata, the vagus nerve passes to the thoracic cavity and then to the abdominal cavity. On its way it gives off branches to the respiratory organs (the larynx, trachea, bronchi, lungs), to the heart and to the digestive organs (the oesophagus, stomach, small intestine, pancreas, liver).

The urinary bladder and the large intestine are supplied with parasympathetic nerves that issue from the lower part of the spinal cord.

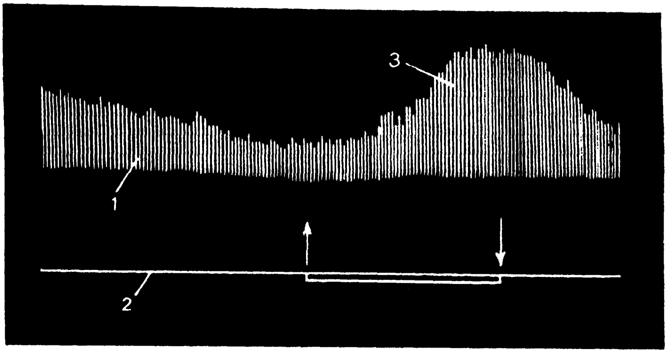

Fig. 127. Influence of the sympathetic system on the work of a muscle:

1 — record of the contractions of a frog's muscle that has been working a long time (fatigued); 2 — indication of the stimulation of a sympathetic nerve (the arrow pointing upward indicates the beginning of the stimulation; the arrow pointing downward indicates the end of the stimulation); 3 — intensified contractions in response to the stimulation of the sympathetic nerve.

The significance of the two-fold innervation of the internal organs. Sympathetic and parasympathetic nerves, carrying impulses to one and the same organs, act upon them in opposite ways. (Table 3).

Table 3

Sympathetic and parasympathetic influences on the activity of the various organs

The name of the organ	Sympathetic influence	Parasympathetic influence
The heart	Intensification and acceleration of the pulsations	Slowing up of the pulsations
The blood vessels of the skin and of the organs in the abdominal cavity.	Constriction	Dilation[1]
The blood vessels of the heart and of the skeletal muscles	Dilation	Constriction[1]
The intestinal canal	Decreased peristalsis	Increased peristalsis
The urinary bladder	Relaxation	Contraction
The eye	Dilation of the pupil	Constriction of the pupil

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[1] The greater part of the vascular area is parasympathetically influenced not through the parasympathetic nerves, but in another, more complex way.

The intensity of the impulses travelling along the sympathetic and parasympathetic systems may change considerably. This immediately produces some change or other in the work of the organs. The two-fold innervation makes the work of the organs more precise and more varied, which, in its turn, provides for the greater adaptability of the organism to its changing needs.

REVIEW QUESTIONS

1. What is the significance of the nervous system?
2. What are the properties of nerve tissue?
3. What is a reflex? What is meant by a reflex arc?
4. What is the importance of afferent impulses?
5. What experiments may prove that inhibition processes go on in the central nervous system?
6. What parts of the brain are developed from the posterior, mid- and anterior cerebral vesicles of the embryo? Find all these parts of the brain in the figures.
7. What is the arrangement of the white and the gray matter in the spinal cord and in the cerebral hemispheres of the brain?
8. What are the chief features in the evolution of the brain of vertebrates?
9. How does the brain of a human being differ from that of a mammal?
10. What are the functions of the medulla oblongata?
11. How is muscle tone maintained, and how is the normal position of the body preserved?
12. What role does the cerebellum play?
13. What are the functions of the fore-brain?
14. How are movements coordinated?
15. What are the peculiarities of the structure and functions of the vegetative nervous system?
16. From what parts of the central nervous system do the sympathetic and parasympathetic nerves issue?

67. The sense organs

Receptors. In all the organs there are receptive nerve endings, or receptors, which transmit excitation to the central nervous system. Afferent impulses, travelling from the receptors, are a necessary condition for the activity of the nervous system, because they maintain its excitability on a certain definite level. Besides this, these impulses serve as the source of the reflex activity of the organism.

Some of the receptors are located within the body and are the receptive agents of irritations aroused in the internal organs, the muscles, tendons, joints; others are found on the surface of the body and serve as receptive agents of stimulations from the external world.

The specialization of the receptors. Receptors of the simplest type as to their structure are the so-called *free nerve endings* (Fig. 128, *1*). They are put into a state of excitation by any violent irritation caused by compression or tension, heat or cold, the action of chemical substances, etc.

Other receptors are of a more complex structure, as a result of which they are very easily affected by the action of particular kinds of stimuli and, at the same time, are protected from the influence of other kinds of stimuli.

Thus, for example, there are nerve endings in the skin which wind themselves round the roots of the hair (Fig. 128, *2*). Since they are located in the deep layers of the skin, these receptors are not easily accessible to the action of such external stimuli as heat and cold. However, they are easily stimulated by the slightest movement of the hair, which may be caused by merely touching the hair lightly, or by the blowing of a gentle breeze on it.

Other skin receptors, enclosed in thick capsules (Fig. 128, *5* and *6*), are not very sensitive to the touch or to pressure; but then, the slightest change in temperature produces excitation in them.

Thus, due to the peculiarities of their structure, the receptors are highly specialized; that is, they can be brought to a state of excitation only by particular kinds of stimuli, specific for each type of receptor.

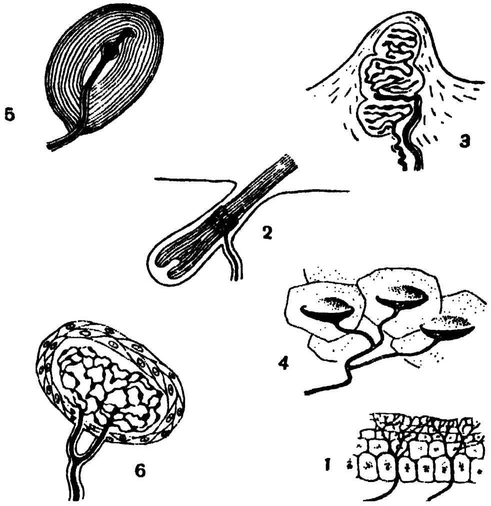

Fig. 128. Skin receptors:

1 — free nerve endings; *2* — nerve ending at the root of a hair; *3* and *4* — tactile corpuscles; *5* and *6* — nerve endings that serve as receptors of heat and cold.

The sense organs. Each specialized receptor is a highly sensitive apparatus for *signalling* the definite changes which go on in the surrounding medium; this gives the organism the possibility to react to stimulations in exact relation to their character. These signalling apparatuses are called the sense organs, because it is by means of them that we feel and perceive the world surrounding us, and also our own bodies.

The reflection of the external world in the consciousness of man. Objects and phenomena in the external world, acting simultaneously on the various sense organs, produce a great many sensations in us. When we hold an apple in our hand, we see it, touch it, smell it and feel its weight; when we bite it, we can determine its taste. Each separate sensation reflects in our consciousness some definite property of the apple.

The source of all our sensations are objects and phenomena that really exist in the world surrounding us. Objects and phenomena act on the sense organs. The impulses aroused in the sense organs are carried to the corresponding parts of the cerebral cortex, where *a psychical process,* called *a sensation,* is aroused. As a result of the complex activity of the cerebral cortex, *perceptions,* based on sensations, are formed, which are reflected in our consciousness — not as separate properties (colour, smell, taste, weight and others), but as things and phenomena as a whole.

Thus, due to the activity of the sense organs and of the brain, we perceive the outside world by reflecting it in our consciousness.

The elimination of errors of the sense organs. Those stimuli to which a given sense organ has adapted itself are called natural or *adequate* stimuli. However, the same type of sensations may be obtained by the action of a stimulus to which a given sense organ is unaccustomed; such stimuli are known as inadequate ones.

Under ordinary conditions, light receptors are inaccessible to any other kind of stimuli except light, which passes readily through the transparent parts of the eye. Light is a natural, adequate stimulus for the visual organ and produces the appropriate sensation in it.

However, there are cases when a sensation of light may be brought about by the action of inadequate stimuli. During an operation, when an eye is removed and the visual nerve cut, the patient has a sensation of a momentary flash of light. A violent blow on the temple, creating a disturbance in the eye and a mechanical irritation of the optic nerve, will also produce a sensation of light (this is how the expression "to see stars" came about). No matter in what way the nerve is irritated, it will send impulses only to the visual area of the cortex of the cerebral hemispheres, and, as a result, a sensation of light will be produced.

It might appear that the creation of the same type of sensations by the action of different kinds of stimuli on one and the same sense organ should result in continual errors and prevent us from getting the correct reflection of surrounding objects and phenomena in our consciousness. However, this is not so in reality.

Firstly, on the basis of his daily experiences in life, a person can easily distinguish between normal sensations, received by the action of adequate stimuli, and sensations that are indefinable, vague, which are created by the action of unusual, unnatural stimuli. We never mistake a noise or a ringing in the ears — the result of a rush of blood to the auditory organ — for sounds in the external environment.

Secondly, sensations received by one organ are always verified by other sense organs.

The practical activity of a person and the experience life gives him, and also the reciprocal control of the sense organs, facilitate the correction of any possible errors, and, as a result, objects and phenomena in the world about us are reflected correctly in the consciousness of a person.

The sensitivity of the receptors. In relation to natural stimuli, the sense organs possess an unusually high degree of sensitivity, often excelling the sensitivity of the most exact physical instruments.

If the atmosphere were perfectly transparent and did not absorb light, then that power of light which a candle has at a distance of over 30 *kil.* would be sufficient for the excitation of the receptors of the eye.

Although the sense of smell is much less developed in a human being than in many animals, a person is sensitive, nevertheless, to the odours of various gaseous substances, the quantity of which contained in one litre of air does not exceed several ten-thousandths or even hundred-thousandths of a milligram.

Adaptation to the strength of a stimulus. A remarkable property of the sense organs is their capacity to change their sensitivity to conform with the strength of the stimulus.

In the bright sunlight, the sensitivity of the visual organ is many thousands of times lower than in the dark. That is why a person coming out of a brightly lighted room into a semi-dark corridor, will see nothing at first. But, gradually, the visual receptors adapt themselves to the weak light, and the person begins to distinguish clearly the objects surrounding him. When the receptors adapt themselves to the darkness, their sensitivity increases to such a high degree that a sudden approach to a bright light blinds the eyes.

On first entering an unventilated room full of people, a person experiences a strong, unpleasant odour. But after some time he, so to say, "snuffs up" the air, and does not feel the bad odour any longer. This is explained by the fact that the sensitivity of the olfactory receptors is lowered.

Adaptation to the strength of a stimulus provides for the normal work of the sense organs under the most varied conditions in the surrounding medium.

68. Receptors of the skin, the mucous membranes and the organs of movement

Skin receptors. As the result of the action of stimuli on the surface of the skin, a person gets sensations of touch, heat, cold and pain. By bringing the point of a well-sharpened pencil in contact with the skin, we find that various receptors exist for each of these sensations: in some spots we get *tactile* sensations; in others, sensations of *heat, cold* or *pain.*

The existence of separate kinds of receptors for the different sensations has been confirmed by observations made of patients. In certain diseases, people lose all tactile sensations, although they retain the sensitivity to pain. On the other hand, in cases of small operations, when a local anesthetic is administered, that is, a small portion of the skin is made insensible to pain, the patient feels the touch of the surgeon's knife, but has no sensation of pain.

The receptive nerve endings are unevenly distributed in the skin. Thus, there are 10 to 15 tactile points or "spots" on a space of one *sq. cm.* of the skin of the leg, while in the different parts of the skin of the face and of the hands the number of "spots" may be 150 or even 300.

The acuteness of the sense of touch is determined, to a great extent, by measuring the smallest distance at which two simultaneous contacts may be felt separately. If the ends of a pair of compasses, separated by 50 or 60 *mm.*, are brought into contact with the skin of the back, only one tactile sensation will be felt, and not two. Only when the ends of the compasses are separated by a greater distance will there be two separate sensations. In various parts of the skin of the forearm, two tactile sensations are felt at a minimum distance of 30 to 40 *mm.* between the ends of the compasses. On the tips of the fingers and on the tip of the tongue two separate tactile sensations are obtained even when the distance between the ends of the compasses is one or two millimetres.

The organ of smell. The organ of smell is located in the mucous membrane of the upper part of the nasal cavity. Its receptors — *the olfactory cells* — are sensitive only to gaseous substances; liquids do not arouse any excitation in them. Therefore, if liquids are introduced into the nose, no sensation of smell may result; an olfactory sensation may be obtained only by "sniffing" at a liquid, when the gaseous particles are separated from the liquid.

Inspired air passes through the lower part of the nasal cavity. However, by means of diffusion, molecules of odoriferous matter get into the region where the olfactory cells are localized.

In animals, the organ of smell, together with the organs of sight and hearing, helps them to orientate themselves in the conditions surrounding them; for example, to scent the presence of an enemy or of prey.

The organ of taste. *The taste buds* (Fig. 129, 130) are located in the mucous membrane of the mouth cavity, and especially on the surface of the tongue. Nerve fibres, issuing from the taste buds, transmit impulses to the medulla oblongata, and from there the impulses are transmitted to *the taste nerve centre* in the cerebral cortex. Only substances in a soluble state may serve as stimuli of the taste receptors: the sweetness of sugar is felt only when it begins to melt in the mouth.

If some fine little paint-brushes, each of them soaked in a solution of a substance with a specific taste, are very carefully brought into contact with various points on the tongue, it is not difficult to determine the existence of separate receptors for ***sweet, bitter, salty*** and ***sour*** substances.

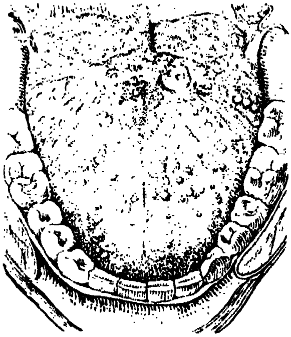

Fig. 129. Upper surface of the tongue (papillae are seen).

In the human being, taste is closely connected with smell. Both of these sense organs help the human being to make a fine discrimination between the various kinds of food substances, and to determine whether they are fit for food or not. In eating onions, apples, bread or any other food, stimuli of varying strength act on the various taste receptors; simultaneously, the olfactory cells are excited by the odour of the stimulus. The result is a complex sensation, which we characterize as the taste of a certain food. In cases of a severe cold in the head, when the olfactory receptors do not function, food seems to be tasteless.

Sensations concerned with the position of the body. At every change in the position of the body, excitation is aroused in ***the receptors*** situated in ***the organs of movement*** — muscles, tendons, the joint capsules and ligaments.

As a result, impulses are created that serve as the source of sensations concerned with the position of the separate parts of the body, with movements performed, and also with the weight of objects, that is, with the amount of muscle tension that is necessary for holding or carrying an object.

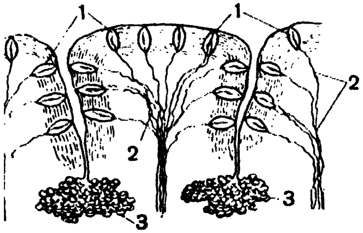

Fig. 130. Diagram of the structure of a papilla:

1 — taste buds; *2* — nerve fibres issuing from them; *3* — mucous glands.

In certain diseases of the spinal cord, afferent nerve fibres, carrying impulses from the lower extremities to the brain, are injured. The efferent nerve pathway, along which impulses travel through the spinal cord to the muscles of the legs, remains intact. The patient may make any movement with his legs and feet. But since he does not receive any sensations from the muscles and joints of the lower extremities, he does not know in what position his legs are — whether they are bent or straightened out. A patient suffering from this disease must always look down at his legs and feet when walking, otherwise he is unable to coordinate their movements, and falls down.

Impulses coming from *the otolithic mechanism* and *the semicircular canals* are of great importance for the sensations that are associated with the movements of the body and with the maintenance of its equilibrium.

Problems. 1. Perform the following experiment: put one hand into warm water and the other into cold water; then put both hands at the same time into a vessel of cool water (of room temperature). How can you explain the sensations of different temperature in the right and in the left hand?

2. Take a horse-hair or a thin bristle about 3 or 4 *cm.* in length, and fasten it to a small stick with a piece of wax or with a small piece of softened bread. Holding the stick in one hand, carefully touch with the hair various parts of the skin on the back of the wrist of the other hand, near the joint between the wrist and the forearm. If you have enough patience, you will note that the contact of the hair will produce a tactile sensation in some places; in others it will feel like a prick, and in still others there will be sensations of heat and cold. How do you explain this?

69. The eye

The structure of the eye. The organs of sight, the eyes (see coloured plate VIII), are set in deep sockets — the orbits, in the skull. The eye-balls move freely in their sockets, or orbits, and can turn easily in various directions with the help of *the eye muscles.* The eyes are protected in front by *the eyelids.* Within the orbits, in the outer corners of the eyes, are *the lachrymal* or *tear glands;* these glands secrete a fluid — the lachrymal fluid — which keeps the surface of the eye-ball moist and thus prevents it from drying up. The excess lachrymal fluid passes off through ducts into the nasal cavity.

The interior of the eye-ball is filled with a semi-fluid, transparent, jelly-like substance — *the vitreous body.*

The wall of the eye-ball consists of three layers or coats.

A thick white opaque coat — *the sclera,* covers the outer surface of the eye; in front, the sclera merges into *the cornea.*

Under the sclera is *the vascular coat* of the eye-ball, which is richly supplied with blood vessels. On the inner surface of this vascular coat there are cells, filled with a black pigment, which makes the wall of the eye impermeable to light.

The iris, situated behind the cornea, is continuous with the vascular coat. The iris contains a great amount of pigment, which gives the eyes their various colours. In the centre of the iris there is a round opening — *the pupil.* The contraction of the smooth muscle fibres of the iris produces constriction and dilation of the pupil. Thus, by becoming larger or smaller, the pupil controls the amount of light that is admitted to the eye.

Just back of the pupil lies the transparent *crystalline lens,* which is doubly convex in shape. With the help of *the ciliary muscles,* the crystalline lens may be stretched or relaxed, that is, it either flattens out more or becomes more convex. Between the cornea and the crystalline lens there is a small space filled with a watery fluid.

The third and innermost coat of the eye-ball is called *the retina*. Extending from the retina are the fibres of the optic nerve, which issues from the posterior side of the eye-ball.

The rods and cones. In the retina there are vast collections of cells — *rods* and *cones* - compactly arranged and sensitive to light rays. It is considered that the number of cones in the human eye is about seven million, and the number of rods — several hundred million.

A ray of light that falls on the retina produces, in the rods and cones, chemical changes which, in their turn, set up excitation. The excitation of the rods and cones spreads firstly to the first row of nerve cells and then passes on to the second row; here the projections of the nerve cells from all parts of the retina unite to form the optic nerve issuing from the eye (Fig. 131). The excitation is directed to the brain along this nerve.

Daylight and twilight vision. The cones of a human being are concerned with colour perception, while the rods are concerned only with the perception of light. The cones have comparatively little sensitivity; they therefore cease functioning at dusk, so that a person cannot distinguish colours at that time. The rods, on the other hand, possess a high degree of sensitivity.

An insufficient quantity of certain vitamins in food, and also other things, may cause a disease called *night-blindness*. This disease destroys the functions of the rods: when there is bright daylight, the sight remains normal, but when it begins to get dark, a person suffering from this disease sees nothing.

The peculiarities of sight of various animals may be explained by the predominance, in the retina, of cones (that is, — of the mechanism of daylight, colour vision), or of rods (the mechanism of twilight, colourless vision). Many night animals (the bat, the owl) have practically no cones in their eyes. On the other hand, the hen, and other birds that see in the daytime, have only cones in their retinae, and almost no rods.

The yellow spot. There is a yellow spot in the centre of the retina, directly opposite the pupil. There are no rods in its central part, but there is an abundance of cones here, packed close to one another. This part of the eye is extremely sensitive to daylight, so that objects whose images fall upon the yellow spot are seen more clearly than other objects. When looking at some object, the eyes, by means of the muscles, are directed in such a way that the image of the object looked at falls on the yellow spot of each eye.

The blind spot. At the point where the optic nerve leaves the retina, there are no cells at all that are sensitive to light. This spot, called the blind spot, is not irritated by light. Therefore, we do not see objects whose images fall upon the blind spot.

It is easy to locate the blind spot by means of a simple experiment. Close the left eye, and look steadily with the right at the cross on the left side of figure 132, holding the book 15 *cm.* away from the eye. Now move the book slowly away from you; at first the small circle nearest to the cross will disappear; then the large circle will become invisible and finally the third; note that when one circle disappears from the visual field, the other two remain visible.

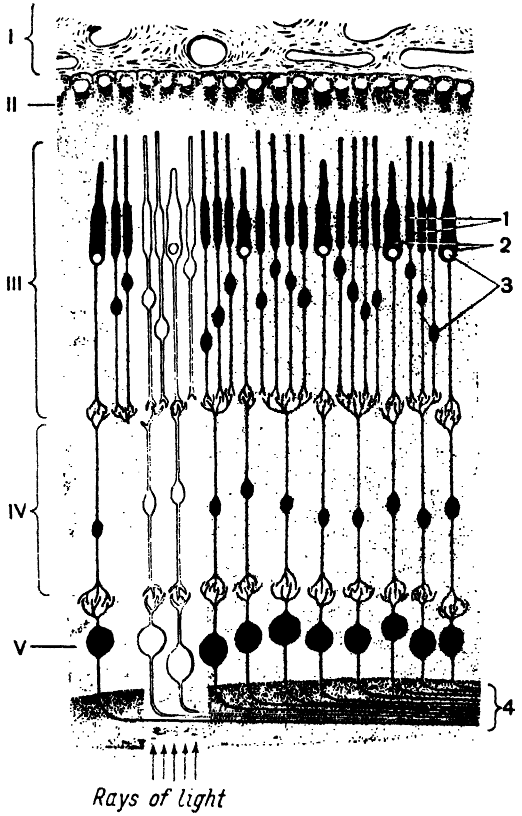

Fig. 131. Diagram of the structure of the retina:

I — part of the vascular coat bordering on the retina; *II* — layer of pigment cells; *III* — layer of rods and cones; *IV* and *V* — two successive rows of nerve cells which receive impulses from the rods and cones; *1* — rods; *2* — cones; *3* — nuclei of the rods and cones; *4* — nerve fibres. The nerve cells of the retina in a state of excitation brought about by the action of light rays are indicated in white.

The images of objects on the retina. Rays of light enter the eye through the transparent cornea, and passing through the watery fluid, the crystalline lens and the vitreous body, fall upon the retina. A pencil of rays of light radiates from each point of an object that we look at. The rays are refracted when passing through the transparent mediums of the eye, and then converge in one point on the retina. Due to the presence of pigment on the inner surface of the vascular coat, the rays are absorbed. This prevents the reflection, or diffusion, of light.

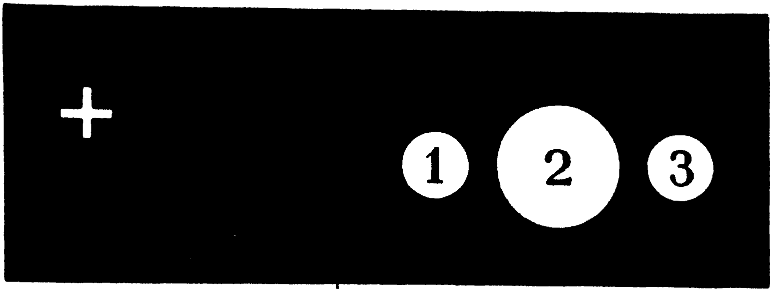

Fig. 132. Experiment by means of which the blind spot in the eye may be found.

Close the left eye and look at the cross in the picture with the right eye. Hold the book at a distance of about 15 *cm.* from the eye. As the book is gradually moved away from the eye, the image of one of the three circles falls on the blind spot; as a result this circle disappears from the visual field.

Pencils of rays from the different points of an object fall upon various points of the retina. As a result, *an inverted and diminutive image* of the object is obtained on the retina (Fig. 133).

Accommodation. The normal human eye can see clearly objects that are close to it, as well as those that are at a distance from it. The ability of the eye to adapt itself to see objects distinctly at varying distances is called accommodation. Accommodation of

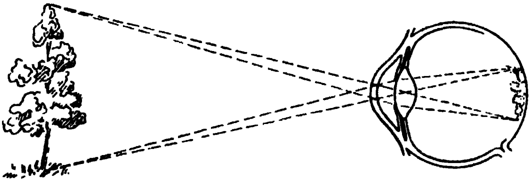

Fig. 133. Diagram showing how the image of an object is obtained on the retina.

the eye is accomplished by means of changes in the convexity of the crystalline lens.

Special fine ligaments pull violently at the crystalline lens and give it a flatter form. When the lens is in this state, parallel rays of light, in other words, rays coming from distant objects, converge on the retina.

When the ciliary muscle contracts, the tension of the crystalline lens is relaxed. The stronger the muscle contraction, the weaker the tension of the crystalline lens and, consequently, the more convex the lens will become. The refraction of the rays is also intensified accordingly. Now it is not parallel rays which are brought to a point on the retina, but radiating rays coming from objects close at hand (Fig. 134).

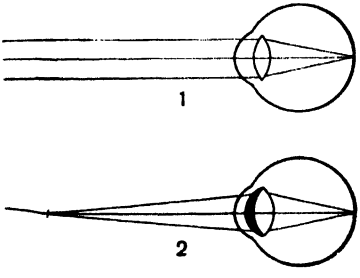

Fig. 134. Diagram of the accommodation of a normal eye:

1 — path of rays from an object seen at a distance (without accommodation); *2* — path of rays when there is maximum accommodation; the blackened part of the chrystalline lens denotes the increase in its convexity.

In children, the crystalline lens is very elastic and its convexity may be increased very much. With age, the elasticity of the lens gradually diminishes; this means that the power of accommodation becomes weaker, so that it is impossible for a person to see objects that are close to him. A child may see an object clearly at a distance of 6 to 8 *cm.* from its eyes. For an adult with normal vision, the nearest point at which he can see objects distinctly is at a greater distance (Table 4).

The elasticity of the crystalline lens of middle-aged people, and especially of old people, is so greatly diminished that the power of accommodation becomes insufficient. In such cases, in order to see objects at a short distance, it becomes necessary to intensify the refraction of light rays artificially by wearing glasses with double convex lenses.

Changes in the power of accommodation (depending upon age)

Age	The distance from the eye to the nearest point at which an object is distinctly seen
10 years	7 *cm.*
20 "	10 "
30 "	15 "
40 "	25 "
50 "	40 "
60 "	1 *m.*
70 "	4 "

Short-sightedness and long-sightedness. With some people, when their eyes are in a state of rest, a pencil of parallel rays from a distant object converges at a point, not on the retina, but either in front of it or behind it. In most cases this is due to the incorrect shape of the eye-ball.

Eyes in which parallel rays converge ***behind*** the retina are called long-sighted (Fig. 135). In cases of long-sightedness, the crystalline lens becomes more convex even when the person is looking at distant objects. In other words, the power of accommodation is partially used up in looking at distant objects. The lens must become very much more convex before a person is able to see objects that are near him. However, it is clear that, with long-sighted people, the nearest point at which an object can be seen distinctly is at a considerable distance from the eyes, even when there is maximum accommodation.

Long-sightedness may be corrected by wearing glasses with double convex lenses; such glasses are also prescribed when the power of accommodation is weakened due to age.

If parallel rays converge *in front* of the retina, a person is said to be short-sighted (Fig. 136). In cases of short-sightedness, only radiating rays, coming from an object near at hand, may come to a point on the retina. Distant objects appear dim and blurred. In severe cases of short-sightedness, the most distant point which the eye can see distinctly is 15 to 20 *cm.* away from it, and sometimes even less. Thus, as a result of accommodation, a short-sighted person may see well objects that are very close up to the eyes. To correct short-sightedness, glasses with concave lenses are prescribed, so that refraction is lessened, thus allowing parallel rays, coming from distant objects, to converge on the retina.

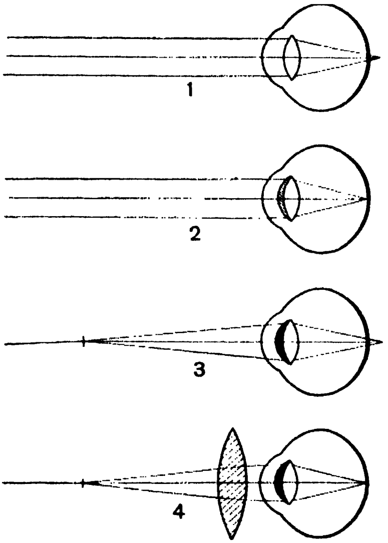

Fig. 135. Diagram of the accommodation of the eye in a far-sighted person;

1 — without accommodation (the parallel rays cross behind the retina); *2* — partial accommodation when looking at a far-off object; *3* — path of rays when there is maximum accommodation; *4* — correction of the sight by means of convex lenses (spectacles).

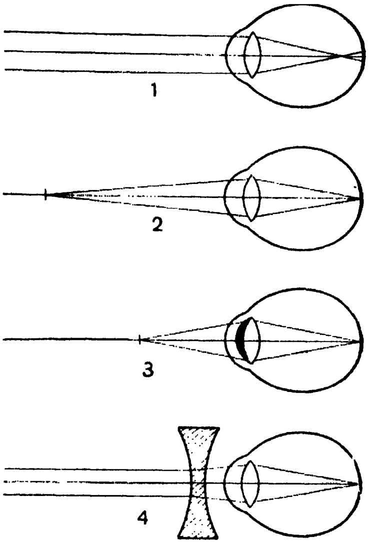

Fig. 136. Diagram of the accommodation of the eye in a short-sighted person:

1 — without accommodation (the parallel rays cross in front of the retina); *2* — the most distant point at which an object is seen clearly (without accommodation)· *3* — the nearest point at which an object is seen clearly (with maximum accommodation; *4* — correction of the sight by means of concave lenses (spectacles).

Questions. What animals that you know have a predominant "rod" vision? What animals have a predominant "cone" vision?

Problems. 1. Use the figure in the book to locate the blind spot in your eye. Answer the following question: How is the blind spot located in relation to the yellow spot? (Which of them is nearer to the nose?)

2. Ask a classmate of yours to stand with his face toward the light. Note the width of both of his pupils. Ask your classmate to close his eyes and to cover them with his hand. In 30 to 60 seconds tell him to open his eyes. Notice carefully the change in the pupils. How can you account for this change?

3. Prick a sheet of paper with a pin, and through the little hole look at some small print in a book, holding the book 2 or 3 *cm.* away from the eye. This experiment must be made under a good light. How can you account for the fact that the letters are distinctly seen? Why do people with poor sight screw up their eyes when they want to see an object more distinctly?

4. Watch the change in the pupils when the eyes are fixed on a distant object and are then quickly transferred to an object close to the eyes. Explain the significance of the constriction of the pupil when looking at an object close at hand.

70. The hygiene of vision

Lighting. A great strain is exerted upon the eyes in reading, and also when performing many kinds of fine work. In order to safeguard the normal activity of this most important sense organ, it is necessary to observe the elementary rules of hygiene for the sight.

The first thing to do is to see that the room we work in is well-lighted. A good light is one that will allow a person with normal sight to read freely a book with small print at a distance of 50 *cm.* from the eyes. If the light is poor, a person is obliged to bend over his work and to strain his eyes very much. Sometimes the light becomes poor because of the layer of dust which covers the window-panes, the electric bulbs or the lamp shade; therefore, it is necessary to keep all these clean.

Too strong a light is also harmful: a bright light blinds the eye and irritates it, and if the irritation continues for a long time, various disorders of the eye may result.

The importance of an even distribution of light and the correct position of the source of light cannot be over-estimated. In artificial lighting, a reflected light is best — when the rays of the lamp are directed upwards to the ceiling and are then reflected back and evenly distributed in the room. The position of the source of light should be such that the light will not blind the eyes, but will be strong enough to light up the place of work well. In writing, the light should not come from the right side, in order to avoid having the shadow of the hand fall on the copybook.

Correct lighting increases the working capacity and diminishes the general fatigue of the whole organism; this is especially true of visual fatigue, usually caused by over-strain of the visual organ. Frequent and prolonged eye strain is the cause of short-sightedness, and weakens the keenness of one's sight.

The hygiene of reading and of writing. When reading or writing, the strain on the eyes is greatly increased as a result of intensified accommodation, and sometimes the strain is also due to an incorrect position of the head. To avoid over-strain of the eyes, one must sit erect without bending the head; the book or copy-book should be placed at a distance of about 35 *cm.* from the eyes, in a slanting position preferably, at an angle of 20° to 30° from a horizontal plane.

It is harmful to read when lying, especially on one's side.

When reading for a long time, one should stop from time to time, even if only for a few minutes, in order to rest the eyes. When resting the eyes from reading, it is useful to fix them upon some distant point to weaken the accommodation.

If the eyes tire very quickly when reading, it is absolutely necessary to consult a doctor and find out whether long-sightedness has not set in.

In cases of long-sightedness, as in short-sightedness, one should wear glasses prescribed by a doctor.

71. The organ of hearing

Perception of sound vibrations. We get sensations of sound, created by the vibrations of various bodies, through the medium of the organ of hearing.

Sound waves, in the form of alternating condensations and rarefactions of the air, spread in all directions from the source of sound, that is, from a vibrating body. The pitch of a sound depends upon the frequency of the vibrations of a body. The human ear may perceive sound waves travelling with a frequency of 20 to 20 000 per second.

The external and the middle ear. The organ of hearing is divided into three parts: the external, middle and internal ear (see coloured plate VIII).

The external ear consists of *the auricle* and of *the external auditory meatus,* which leads to the thick part of the temporal bone, where the middle and the internal ear are located. A thin but very compact *tympanic membrane* (the ear drum) separates the auditory meatus from the cavity of the middle ear, where a chain of three small bones, the auditory bones, are located; because of their shape, these are called *the hammer, the anvil* and *the stirrup.* The hammer is attached to the inner surface of the tympanic membrane, while the stirrup is firmly fixed to the membrane which closes up the opening leading to the internal ear.

In order that sound vibrations should be transmitted normally, it is most important that the air pressure in the middle ear should be equal to the atmospheric pressure. The two pressures are equalized through the medium of *the Eustachian tube* — a canal which unites the cavity of the middle ear with the cavity of the pharynx. The external opening of the Eustachian tube is usually closed, and is opened only at the moment of swallowing. In cases when there are rapid changes in the pressure of the surrounding atmosphere (for example, in the sudden descent of an aeroplane or in parachute jumping), it is advisable to make quick swallowing movements in order to equalize the pressure in the middle ear.

The internal ear. The internal ear has a very complex structure.

Not all of the internal ear is part of the organ of hearing, but only *the cochlea* — a long canal coiled up upon itself in a spiral, and filled with a fluid. A thin membrane, called *the basilar lamina,* and consisting of thousands of little fibres of various length and thickness, extends along the whole length of the canal, dividing it into an upper and a lower part.

The other part of the internal ear, consisting of the otolithic mechanism and semi-circular canals, is an organ of equilibrium and has nothing to do with hearing.

Excitation of the receptors of the ear. Sound causes the tympanic membrane to vibrate; the vibrations created are transmitted, through the auditory bones, to another membrane covering the entrance to the internal ear. The vibrations of this second membrane are transmitted to the fluid which fills the internal ear, and through the fluid are passed on to the little fibres of the basilar lamina.

Not all of the little fibres are set into vibration in response to each sound, but only a certain definite portion of them. In this respect, they resemble the strings of a piano. If a certain tone of a definite pitch is produced near an open piano — let us say, the tone "do" — the string tuned to that tone will begin to vibrate and will give out a tone of the same pitch. This phenomenon is called resonance. The separate sensations of various sounds are based on resonance.

The vibration of the little fibres produces irritation in special sensitive cells, which enter into the composition of the so-called *spiral organ,* located on the basilar lamina and extending along its whole length. Afferent nerve fibres, issuing from the sensitive cells, carry the impulses created in them to *the auditory centre* in the cerebral cortex.

Injury of any part of the basilar lamina will bring about loss of hearing in relation to sounds of a corresponding pitch.

Questions. 1. Give some examples of errors of the sense organs (besides those mentioned in the text-book).

2. Explain why we get a correct reflection of the external world in our consciousness, in spite of errors of the sense organs. What helps to correct the errors in each of the examples you have taken?

Problem. Make a table, similar to the one given below, showing the sensations received from the organs of sight, the organs of hearing, the otolithic organ, the semi-circular canals, the organs of smell, taste and touch, and also from the muscles and tendons.

The name of the organ	The sensation obtained
The visual organ — the eye.	Light, colour, distance (measured by the eye), the size and shape of an object.

REVIEW QUESTIONS

1. What role do the sense organs play in our perception of the world surrounding us?
2. Give some examples of the adaptation of the sense organs to stimuli of various strength.
3. Explain the structure of the eye and the significance of each of its separate parts.
4. How does the eye adapt itself in order to see objects that are close to us or far from us?
5. Give some instances of conditions under which accommodation is destroyed. Explain each case. How may the defects of accommodation be corrected artificially?
6. What are the chief rules of the hygiene of vision?
7. What is the structure of the ear?
8. How is excitation of the receptors of the ear produced?

72. Setchenov and Pavlov — the founders of the science of higher nervous activity

I. M. Setchenov. In the history of Russian physiology there is a famous date: it is 1863, when Setchenov's article, "Cerebral Reflexes," was published in a journal of the time.

Ivan Setchenov, one of the greatest representatives of Russian science, was born in 1829. On graduating from the medical department of the Moscow University, he went abroad in order to become acquainted with the work of outstanding German and French physiologists; but in the very first few years of his residence there, he showed himself to be an independent and talented scientist and soon became known as one of the greatest physiologists of the period. On his return to Russia, Setchenov was made a professor of the Petersburg Medico-Surgical Academy. At his lectures he always performed a great number of experiments, a procedure which was very unusual at that time. The advanced ideas of Belinsky, Hertzen and Chernyshevsky had a great influence upon Setchenov, and he became a convinced materialist. Setchenov, an active figure in the social life of his country, and a patriot who loved his native land profoundly, developed Russian science on a materialistic basis and, to the last day of his life, propagated the materialistic world-outlook.

Setchenov's interest in psychology dates back to his early student days, when he began to devote himself with especial zeal to the question of the physiological basis of psychical phenomena.

Many ages ago there arose the belief that feelings, thoughts and desires were connected with the existence of a "divine spirit", which left the body the moment a person died. Philosophers-idealists and churchmen tried most seriously to solve the problem as to the exact "place of abode of the soul" in the organism. There was no doubt whatever in their own minds that the soul was something not material, and that it was not subjected to the laws of nature.

I. M. Setchenov.

The idea of the "immortality of the soul" is closely connected with religious belief. This idea has held sway for thousands of years, because the ruling classes have always used religion "as a means of dominating and of keeping the lower classes in subjection." (Engels.) The belief in a soul and in a life beyond the grave was of prime importance to the ruling classes, because it served to divert the attention of the poor from the struggle against their oppressors.

That is why the scientists-idealists said that the soul was not subjected to the body, and that psychology had nothing to do with physiology. They considered that it was impossible to make a study of psychical activity by means of experiments performed on the brain.

However, it was Belinsky who pointed out that "psychology, without the support of physiology, was as worthless as physiology, without a knowledge of the existence of anatomy."

Setchenov was the first to make a bold attempt to give a physiological explanation of the psychical activity of a human being. This attempt was preceded by a very remarkable scientific discovery that immortalized the name of Setchenov. Setchenov removed the cerebral hemispheres of a frog; then he made a cross-cut in the region of the inter-brain and determined the speed with which reflex actions appeared in response to the irritation of the frog's leg with an acid. When some crystals of sodium chloride were put on the cut part of the brain, the reflexes were clearly retarded. This phenomenon, which received the name of the

"*Setchenov inhibition,*" proves that the brain can inhibit reflex actions.

Setchenov understood that his discovery of the inhibition of reflexes must be of the greatest importance in explaining the complex work of the human brain, with which the psychic state and the consciousness are connected.

In his well-known article, "Cerebral Reflexes," Setchenov proves with great mastery that *reflexes,* which may be either intensified or inhibited, depending upon the conditions involved, lie at the basis of all manifestations of the psychical activity of a human being.

According to the testimony of Timiryazev, the advanced materialistic views of Setchenov set the minds of Russian naturalists aflame. One of Setchenov's pupils, the outstanding Russian physiologist Vvedensky, wrote about "Cerebral Reflexes": "Evidently there was not a single intelligent reader in the sixties and seventies of the preceding century who had not read this book. It was so popular among the youth of the university that it was considered a matter of absolute necessity for one's general education to become acquainted with this work. It was natural that the book should leave a profound impression upon the readers."

The attitude of the tzarist government to the activity of Setchenov was of quite a different nature. The book "Cerebral Reflexes" was denounced as highly dangerous and was therefore to be confiscated. Setchenov himself was at last forced to leave the Medico-Surgical Academy. Setchenov worked in Odessa for several years and then returned again to Petersburg, where he was made professor of physiology at the University. The tzarist government continued to persecute the great scientist; it strove to keep the student mass, and the whole Russian public in general, from the influence of advanced materialistic ideas, and finally forced Setchenov to leave Petersburg again. For three years the world famous scientist could not get a laboratory in which to perform his physiological experiments. One of the greatest German professors begged Setchenov to leave his native land and to make his residence in Germany in order to work there permanently; Setchenov refused. Just at that time he was invited to work at the Moscow University. Again came intensive creative activity. Now he made a study of physiological questions connected with the working capacity and with fatigue, and thus gave a physiological basis for the demand of the working class for the 8-hour workday.

In the course of his whole scientific activity Setchenov always strove to make materialistic science the property of the people. He wrote a great number of scientific-popular articles and books; he delivered very many popular lectures. Two years before his death, at the age of 74, he began, with great enthusiasm, to give a course of lectures at the Prechistenski workers' clubs in Moscow.

However, after several months, the tzarist government prohibited the great scientist to lecture before audiences of workers.

Setchenov died in 1905.

The study of higher nervous activity by I. P. Pavlov. The work begun by Setchenov was continued by another great Russian scientist — I. P. Pavlov. The theory of the relation between the higher manifestations of nervous activity and the reflexes of the brain was the basis for all of Pavlov's remarkable experiments, performed in the course of many years.

Before Pavlov, no one had really made a study of the physiology of the cortex of the cerebral hemispheres as an organ of higher nervous activity. No method existed for studying the work of the cortex of the hemispheres with the exactness with which the contraction of the muscles, or the secretion of gastric juice, is studied. And scientists continued in their belief that the physiological investigation of higher nervous activity, with which the behaviour of an animal is connected, was impossible.

Simple facts, familiar to everybody, gave Pavlov the idea of the correct method to be used in studying higher nervous activity. For several years Pavlov investigated the salivary secretion of dogs by means of fistulae applied to their salivary glands. He paid special attention to the fact that saliva is secreted not only in response to a direct stimulation, by food, of the mucous membrane of the mouth cavity, but also by the action of other stimuli, which are, as it were, signals of the approach of food to the mouth. Such signals may be the odour and sight of food, the footsteps or voice of the person who is in the habit of feeding the dog, etc.

This applies not only to the work of the salivary glands, but to any activity of the organism. Thus, for example, a person flourishing a stick or a whip is a signal of a painful stimulation, and arouses a defensive reaction in the animal — the dog tries to protect itself or to run away.

Pavlov demonstrated by experiment that the influence exerted by such signals is connected with the activity of the cortex of the cerebral hemispheres: if the cortex is removed, this influence ceases completely. A dog with the cerebral cortex removed does not react to the presence of the person who feeds it, nor to the sight or smell of food, nor to the presence of an enemy. It snaps and snarls in response to any touch. It begins to secrete saliva only after food is put into its mouth.

Pavlov used his investigation of the reactions to signalling stimuli as the foundation for the study of higher nervous activity. The reactions of any organ might have been taken for study. Pavlov chose the salivary gland. The application of a fistula to the salivary gland does not disturb the normal activity of the organism; at the same time, it gives the experimenter an opportunity to observe the character and strength of the reaction easily:

it is possible to measure the exact quantity of saliva secreted in any period of time, even the shortest.

The secretion of saliva in response to various signals is an index of the processes going on in the cerebral cortex. And Pavlov, using his own method, succeeded in making a study of these processes and in determining the basic laws that govern higher nervous activity.

73. Conditioned and unconditioned reflexes

Unconditioned reflexes. A reflex secretion of digestive juices will begin in response to the introduction of some meat into the mouth of a grown dog, as well as into that of a puppy who has never tasted meat. If the dog's leg is irritated by an electric current, it will draw it away. These *inborn* (constant) reflexes Pavlov called unconditioned reflexes, because they always appear and do not require any additional conditions to produce them.

The arcs of unconditioned reflexes do not pass through the cerebral cortex, but through other divisions of the brain; unconditioned reflexes continue to appear even after the cortex has been removed.

Conditioned reflexes. A dog with its hemispheres intact will secrete saliva even at the mere sight of food. This is also a reflex. However, it differs essentially from the reflex produced when the same food is introduced into its mouth.

If a puppy does not as yet know the taste of meat, the mere sight of meat will not arouse a saliva secreting, or salivary, reflex. The reflex at the sight of meat will appear only after it is fed with the meat that has been shown to it. In the same way, the salivary reflex may occur at the sight of a bowl, but only if the dog has already received its food in that bowl.

The chief feature of such reflexes is that they are not inborn, but *acquired,* and are continually being produced in the course of the whole life of the animal. These reflexes Pavlov called conditioned reflexes, because certain specific conditions are necessary for their formation.

Conditioned stimuli as signals. A conditioned reflex may be built up by any stimulus; it appears to make no difference whatever to the animal what the stimulus is, if it becomes the signal for an unconditioned stimulus — that is, for a stimulus that brings about an unconditioned reflex.

The sight of a bowl that has become the signal for food produces a salivary conditioned reflex. In exactly the same way, any sound stimulus (for example, the sound of a horn) may become a food signal, if it is accompanied each time by feeding, and the animal ceases to be indifferent to the sound. In other words, a conditioned reflex is produced: the sound of the horn alone is enough to start salivary secretion.

The same stimulus (the sound of the horn) may serve as a pain signal and bring about a conditioned defence reflex. To do this, the sound must be accompanied by the action of a corresponding unconditioned stimulus — for example, the irritation of the animal's leg by an electric current. When the current is applied, the dog jerks its leg away and begins to yelp — this is an unconditioned reflex. If the sound of the horn is accompanied by the application of the current, then, after some time, a defensive reaction is produced by the sound of the horn alone.

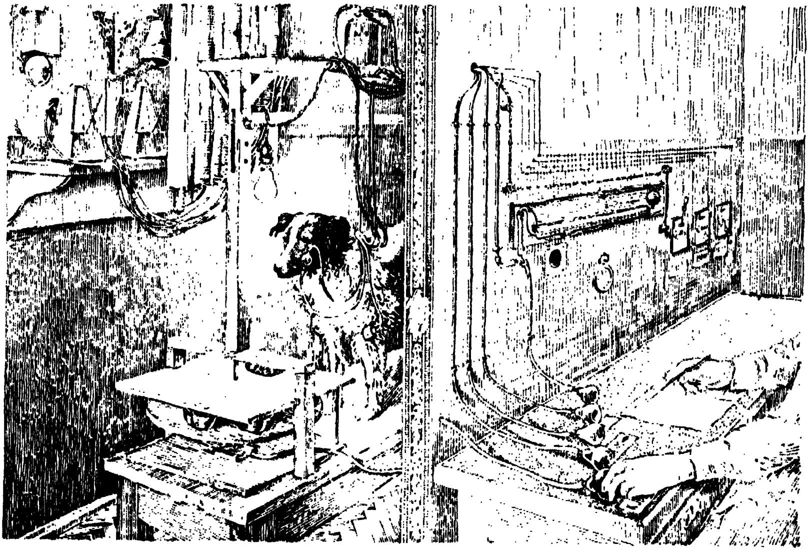

Fig. 137. Chamber for studying salivary conditioned reflexes.

Light is turned on (a conditioned stimulus); a trough of food is placed before the dog (an unconditioned stimulus). Other stimuli are seen: two metronomes, two bells, a skin stimulus — "toucher". In front of the experimenter there is a board with a recorder of the salivary secretion.

The conditions under which experiments are performed. Experiments for studying conditioned reflexes require special conditions. All extraneous stimuli must be carefully eliminated, since any one of them may turn into a definite signal, or may simply interfere with the normal procedure of the experiment.

For that reason, the dog experimented on is placed in a special chamber, through the walls of which no external sounds can pass. The experimenter is outside the chamber, watching the reactions of the animal with the help of special apparatus (Fig. 137). The saliva flow may be measured with great exactness by means of the movement of the liquid along the scale of a recorder, which, with the help of air transmission, is connected with a little glass bulb, attached to the fistula of the salivary gland. By pressing upon various rubber bulbs, it is possible, without entering the chamber, to set a little trough before the dog and then to remove it, and to set into motion the various stimuli in the chamber, for example, a bell, an electric bulb, "a toucher" (an apparatus for producing tactile sensations), a pain stimulus, etc.

The building up of conditioned reflexes. Let us say we want to build up a salivary conditioned reflex by means of a bell. To do this, the bell is set ringing; in 15 or 30 seconds, while the bell is still kept ringing, an unconditioned stimulus is associated with the bell stimulus; in other words, a trough is moved in front of the animal by pressing one of the rubber bulbs. Then the ringing of the bell is stopped at the same time that the trough is removed.

It goes without saying that there is an abundant flow of saliva in the dog at the time it is eating. If this experiment is repeated many times, the secretion of saliva will begin before the food is presented — it will start at the ringing of the bell only.

Thus, the repeated association of feeding with the sound of the bell turns the latter stimulus into a food signal — it becomes a conditioned stimulus. Now the sound of the bell alone is enough to start the flow of saliva.

In order to preserve the conditioned reflex thus built up, it is necessary to reinforce it from time to time by associating it with an unconditioned stimulus — in this case, the trough of food. If this is not done, the conditioned reflex will weaken and will then be entirely extinguished.

Conditioned associations in the cerebral cortex. Food introduced on the tongue irritates the taste receptors. The impulses created are directed along the afferent fibres of the taste nerve to the salivary centre of the medulla oblongata, and produce a zone of excitation there; from the medulla oblongata, responsive impulses travel along the efferent fibres to the salivary glands. Thus, the arc of the salivary reflex passes through the medulla oblongata. At the same time, impulses also reach the centres for taste of the cerebral cortex, where, as in the medulla oblongata, a zone of excitation is also aroused (Fig. 138, *I*). However, the participation of the cerebral cortex is not a necessary condition for the formation of salivary reflexes, or of other unconditioned reflexes.

In order to build up a conditioned reflex, let us introduce the action of a new stimulus — the light of an electric bulb (Fig. 138, *II*). This stimulus will also produce zones of excitation in the cerebral cortex, as well as in the lower divisions of the brain. In response to the action of the light, an "orienting" (focusing) reflex may be produced — the dog turns its head in the direction of the bulb and pricks up its ears, all attention. This is an unconditioned reflex; its arc does not pass through the cerebral cortex.

If the action of the new stimulus (the light of the electric bulb) is associated with the action of an unconditioned stimulus (food), two zones of excitation appear in the cortex of the cerebral hemispheres: the first, in the centre for vision of the cortex, and immediately following the first comes the second — in the centre for taste; association arises between them. The more frequently both sections of the cortex are stimulated simultaneously, the more fixed the association becomes. Soon the association between the two sections in the cortex becomes so strong that the excitation, produced by the light of the bulb in the first section, will spread to the second; this brings about a flow of saliva, although the trough of food has not yet been placed before the dog.

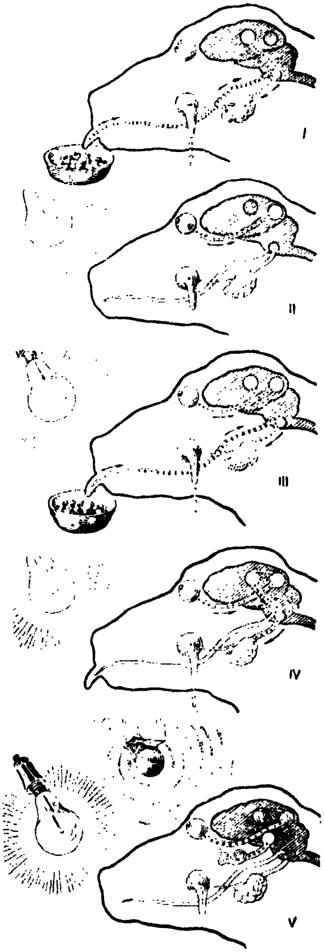

Fig. 138. Diagram of unconditioned and conditioned reflexes:

I — an unconditioned salivary reflex; *II* — the action of an indifferent light stimulus (zone of excitation in the visual area of the cerebral cortex; the orienting reaction is not shown); *III* — the building up of a conditioned reflex; reinforcement of an indifferent stimulus by a conditioned one (there are two simultaneous zones of excitation in the cortex); *IV* — the conditioned reflex; *V* — inhibition of the conditioned reflex (creation of a zone of excitation in the auditory area of the cerebral cortex, and the inhibition of other regions of the cerebral cortex).

The arc of this conditioned reflex passes through two sections of the cerebral cortex: at first, a zone of excitation arises in a definite part of *the centre for vision;* then, as a result of the association established between the two points of the cortex, the excitation is transmitted from the centre for vision to the corresponding part of *the centre for taste,* and from there, through *the salivary centre* of the medulla oblongata, to *the salivary glands* (Fig. 138, *III* and *IV*).

Thus, in the process of the formation of a conditioned reflex, an association is established between two definite points in the cerebral cortex, as a result of which excitation of the first point absolutely involves the excitation of the second. Such an association is called a conditioned association.

Comparison between unconditioned and conditioned reflexes. Unconditioned reflexes need no special building up. They are inborn, hereditary, and are the same in all animals of a given species; they might therefore be called specific. They have definite, constant arcs, which do not pass through the higher divisions of the brain, but through its *lower* parts.

Conditioned reflexes, in contrast to unconditioned reflexes, are acquired by an animal in the course of its life, and are built up under definite conditions — above all, by the repeated reinforcement of a new stimulus by an unconditioned stimulus associated with it. In order to form a new conditioned reflex, the excitability of the corresponding nerve centres must be of a high enough degree, and no extraneous stimuli must interfere.

Built-up conditioned reflexes may last for a long time only in case they are reinforced, even though that is done at rare intervals. Without reinforcement they are extinguished. Consequently, conditioned reflexes are acquired and temporary; their formation depends upon the conditions in which the animal finds itself. Therefore, conditioned reflexes of different types may be produced not only in the various animals of a given species, but even at different times in one and the same animal. Such reflexes may be called individual reflexes to differentiate them from the specific kind.

For each new conditioned reflex, new arcs are created which always pass through the *higher* divisions of the brain (in dogs — through the cortex of the cerebral hemispheres).

The significance of conditioned reflexes. In the course of its life, every animal meets with a vast number of the most varied kinds of stimuli. Many of these become conditioned, serving as signals of the different phenomena in the external world — phenomena which are of importance to the organism in one way or another. A change in the conditions in which an animal finds itself brings about a change in the reflexes — some of the old conditioned reflexes vanish and new ones appear.

As an example, let us take a house dog, in whom a number of definite conditioned food and defence reflexes have been built up. Many of these reflexes will disappear, if the dog leaves its home and becomes a wandering street dog. To take the place of those reflexes that disappear, others arise, depending upon the new conditions in which the dog finds itself.

The conditions of life never remain constant. The nervous system always responds to every change in the external environment by the formation of new conditioned reflexes and the extinction of old ones, which now do not receive any reinforcement on the part of unconditioned stimuli. It is just this fact that makes conditioned reflexes so important, namely, the fact that they help an animal to *adapt* itself to the most varying and continually changing conditions of existence.

Questions. 1. Give some examples of unconditioned reflexes, besides those given in the text-book.

2. Give some examples of conditioned reflexes, besides those given in the text-book, and point out the unconditioned reflexes on the basis of which they were built up.

74. The processes of excitation and inhibition in the cerebral cortex

The inhibition of conditioned reflexes. There is a continual interaction of the processes of excitation and inhibition in the cortex of the cerebral hemispheres, as well as in all the other parts of the nervous system. The appearance in any part of the cortex of a zone of intense excitation arouses a reverse state — that is, inhibition, in some of its other parts. If a sudden loud sound is heard at the same time that a conditioned stimulus (the light of an electric bulb, for instance) is in action, the conditioned reflex will be inhibited. The sound produces a strong zone of excitation in the auditory centre of the cortex and this brings about inhibition in all the other sections, including the centre for vision; as a result, the light of the electric bulb, which, under ordinary circumstances, would call forth a reflex secretion of saliva, now fails to give any reaction whatsoever (Fig. 138, *V*).

Such inhibition, produced by the action of any extraneous stimulus and not requiring any special building up, Pavlov called *unconditioned* inhibition.

Conditioned inhibition. In other cases, inhibition does not appear at once, but is built up gradually under certain definite conditions. Such inhibition, an example of which is the extinction of a conditioned reflex in the absence of any reinforcement, Pavlov called conditioned inhibition.

Let us suppose that a salivary conditioned reflex is formed in a dog when the skin of its right thigh is scratched. The application, every few minutes, of only one conditioned stimulus (scratching) without reinforcing it by feeding the animal, at first brings about a decrease in the quantity of saliva secreted each time the stimulus is applied; and then salivary secretion ceases altogether.

It would seem that the extinct reflex should not appear on the following day. But, actually, the reflex flares up with new strength; again we observe the flow of saliva at the scratching only. The restoration of the reflex may be explained by the fact that, during extinction, — that is, when there is a lack of reinforcement of the conditioned stimulus by an unconditioned one, inhibition, instead of a state of excitation, is aroused in the corresponding section of the cerebral cortex; this state of inhibition also causes the reflex to weaken or to disappear altogether. The reflex will not appear so long as the state of inhibition continues in a given point of the cortex.

Differentiation of stimulations. Experimentation has established the fact that impulses from various parts of the skin travel to the different points of the cerebral cortex. If a conditioned salivary reflex to the scratching of the right thigh has been built up in a dog, excitation is aroused in the corresponding point of the cortex, and is then transmitted to the food centre in the cortex. Let us now try the "toucher" (that is, a little apparatus used for irritating the skin) and apply it, not to the right thigh of the dog, but to its left paw, the trunk of its body or any other part of its skin. Under these conditions, also, the scratching will bring about a conditioned reflex, although the stimulation of a fresh part of the skin had never before been reinforced by the action of an unconditioned stimulus.

This is due to the fact that excitation, after reaching a definite point in the cerebral cortex, does not remain there, but spreads, or *irradiates*, to the neighbouring parts. Therefore, when a conditioned reflex is built up, not only that point in the cortex excited by the stimulation of the skin of the right thigh is coupled with the food centre, but also the region surrounding it, which corresponds to the other parts of the skin.

However, the spreading of excitation becomes gradually less noticeable; it *concentrates* in a limited section. This process of the concentration of excitation can be very much accelerated by attaching several "touchers" to various parts of the dog's skin, and, after that, by giving the animal food only when its right thigh is scratched; but no food must accompany the stimulation of other parts of the skin. In this experiment the secretion of saliva begins after some time, but only when the reinforced part of the skin is scratched. If other parts of the skin are irritated, a conditioned inhibition will arise in the corresponding points of the cerebral cortex, and there will be no reflex.

Thus, the differentiation of similar stimulations is established in the cerebral cortex: one of them sets up a conditioned reflex, while the others cause inhibition in the corresponding point of the cerebral cortex, and produce no reflex. Differentiation of similar signals may achieve a very high state of perfection. With a ticking metronome (an apparatus used for beating time) it is possible to observe the differentiation, by the nervous system of a dog, between 96 strokes and 100 strokes per minute: if the 100 strokes are reinforced by feeding, and the 96 are not reinforced, the secretion of saliva begins only with 100 strokes of the metronome. Such a fine differentiation of the frequency of the strokes is impossible by a human being.

The analysis and synthesis of stimulations. The differentiation — in other words, the analysis of stimulations, first begins in the sense organs, because the different stimuli (light, sound, etc.) act on the various receptors. More than that, a still finer analysis goes on in each sense organ. Thus, the separate nerve endings of the auditory nerve are excited by sounds of various pitch. Therefore, a fine differentiation in the pitch of a sound is already set up in the organ of hearing. Such fine differentiations of stimulations are set up in the other sense organs also.

However, the differentiation of stimulations is not limited to the activity of the sense organs. The impulses aroused in the sense organs are conveyed to the corresponding parts of the cerebral cortex; here zones of excitation and inhibition appear, which lead to still greater differentiation of stimulations.

The analysis of stimulations, originating in the sense organs and terminating in the cerebral cortex, is a unified process. That is why Pavlov united the receptor, the afferent pathway from the receptor to the cerebral cortex, and the corresponding parts of the cerebral cortex under one designation: *the analyser.*

The sense organs are the external, or peripheral ends of the analysers, while the cortex of the cerebral hemispheres is their internal, or central end.

Not only differentiation (analysis), but unification (synthesis) of similar stimuli takes place in the cerebral cortex. Synthesis is based on the ability of the processes of excitation and inhibition to spread, to irradiate. Let us take an example. A conditioned defence reflex — the lifting of the paw, has been built up in a dog. The unconditioned stimulus is an electric current, producing a pain stimulation; the conditioned stimulus is the tinkling of a small bell. When a large bell with a lower tone is used for the first time, the same reaction is produced — the dog lifts up its paw. In this case, unification (synthesis) of the two similar stimuli takes place in the cerebral cortex.

Association and interrelation of impulses, which serve as signals of the various phenomena in the external world, as well as in the organism itself, always lead to the unification (synthesis) and the differentiation (analysis) of stimulations.

The vital significance of the processes of analysis and synthesis of stimulations is perfectly clear. They provide an animal with the possibility of *orientating* itself in the conditions in which it finds itself, and to react correctly to varying stimuli. We have only to think of the behaviour of wild animals, living in freedom. To them every rustle, every shadow, the faintest odour, the slightest vibration of the air — all serve as signals of the proximity either of food or of danger. Only as a result of synthesis and, at the same time, of the fine differentiation of stimulations, can an animal notice threatening danger, find prey, and produce a reaction, appropriate to the condition, in time.

The movement of the processes of excitation and inhibition. Years of investigation and study of conditioned reflexes gave Pavlov and his co-workers the possibility to determine the nature of the movement of the processes of excitation and inhibition in the cerebral cortex, and the laws governing this movement. Impulses from all parts of the body are continually travelling to the different cells of the cortex. Each zone of excitation and of inhibition aroused by these impulses does not remain inactive; it *irradiates,* that is, it spreads to other parts of the cortex. This phenomenon of irradiation of excitation and of inhibition is one of the basic laws of the activity of the nervous system.

Another basic law is *the reciprocal induction* of the processes of excitation and inhibition — that is, the induction of a reverse state. Thus, in response to the appearance of a zone of excitation in the cerebral cortex, a state of inhibition arises at other points in the cortex. The inhibition prevents the spread of the process of excitation to all parts of the cortex, and forces excitation to become *concentrated* again at the point where it originated. But it is here that excitation is finally extinguished, and is replaced by the reverse process — inhibition.

Thus, the processes of excitation and of inhibition are constantly interacting with each other. As a result, a very complex interlaced pattern, or, as Pavlov called it, a mosaic of the processes of excitation and of inhibition is formed in the cortex of the cerebral hemispheres. This mosaic is in a state of continual movement: zones of excitation and of inhibition replace each other, now appearing, now again disappearing, in the various points of the cerebral cortex.

The importance of Pavlov's theory of conditioned reflexes. Pavlov's scientific theory of conditioned reflexes created a new chapter in physiology — the materialistic study of higher nervous activity.

Pavlov showed that the cerebral cortex, as an organ of higher nervous activity, could be studied by physiologists as profoundly and in as detailed a manner as any other part of the body. Soviet scientists, headed by Pavlov, proved that all *higher nervous activity* of animals, as well as of man, is based on the processes of *excitation* and *inhibition* — processes characteristic of other divisions of the nervous system. The continued study of these processes in the course of many years not only enabled them to determine the laws governing the behaviour of animals, but it also showed that the cerebral cortex is an organ by means of which the organism adapts itself to its environment. It is this that constitutes the vast biological importance of Pavlov's scientific theory of conditioned reflexes.

By applying exceptionally strong stimuli, and also by applying a special combination of reinforced conditioned stimuli and unreinforced conditioned stimuli that are closely related to them, Pavlov brought about, in dogs, a diseased state of the cerebral cortex very similar to that which arises in a human being during certain nervous and mental (psychic) diseases. This gave Pavlov the opportunity to explain the physiological processes produced in the cerebral cortex during such diseases and to devise methods for their treatment. Pavlov's theory of higher nervous activity has led to a clear and simple understanding of the subject; it has explained the phenomenon of sleep, hypnosis, and certain psychical diseases, and in so doing it has refuted the religious fables *about the "immortality of the soul,"* of "divinity" and "prophetic" dreams, of people possessed by a so-called "evil spirit," of "miraculous" cures, and other things of a similar nature.

Problem. Give some examples of the inhibition of conditioned reflexes taken from life.

75. Specific features of higher nervous activity in man

The basic difference between man and animals. The basic condition of the life of a human being is labour, connected with the production and utilization of tools. It is labour, namely, that created man. It was in the process of *labour* that all the basic features of the human organism, which differentiate it from that of animals, were formed and perfected. The joint, collective labour activity of people made it possible for articulate speech to come into existence and to develop. Closely connected with labour and articulate speech is the remarkable development of the human brain — the appearance of new divisions in the cortex of the cerebral hemispheres and the modifications in the work of all its other parts.

"At first it was work," said Engels, "and then articulate speech together with work that were the two most important stimuli, under the influence of which the brain of the ape was gradually transformed into the human brain..." And, as a result, man rose to a higher stage of development in comparison with the rest of the animal world. The psychic state of man — in other words, his sensations, thought, emotions, desires, is immeasurably higher than that of animals. This higher stage of development of the psychic state so peculiar to man is called consciousness.

The psychic state of animals and human consciousness. The striving to achieve some aim — *purposefulness*, is characteristic of the conscious activity of man. A human being sets a purpose before himself and finds a way of attaining it.

"The spider performs operations that are very much like those of a weaver, and the bee, in the construction of its wax cells, brings some human architects to shame. But the worst architect differs from the most skilful bee at the very outset in that the human architect, before building a cell out of wax, has already constructed it in his head. At the end of the process of work, a result is obtained which the worker already had a conception of at the beginning of this process..." (Marx)

In these words of Marx is revealed, with great clarity, the difference between human consciousness and the psychic state of animals. Both man and animals reflect the phenomena of the external world in their psychical activity. However, man, in reflecting the world in his consciousness, generalizes the phenomena observed and establishes the laws governing their course. This gives him the opportunity to utilize them for his own purposes, to subject nature to himself and, in the process of his labour activity, to remake the world. Engels said: "... the animal only *makes use of* the external world and introduces changes into it simply by virtue of its own presence in that world; but man, when bringing changes into it, compels it to serve his own aims, and *dominates* over it."

There is no doubt whatever that the higher animals possess an elementary, rudimentary thinking capacity. However, only human thought gives the possibility, not only to generalize the results of observation, but to draw conclusions in regard to other phenomena which were not directly observed, and also to foresee the course of events. Conscious thought developed in man in connection with the production and application of the instruments of labour, at first of a very simple kind, and then of an ever increasing complexity.

Consciousness as a socially conditioned phenomenon. In the course of the history of man, consciousness, which developed in the process of labour activity, depended on the method of procuring food, clothing and other means of existence — in other words, on the instruments of labour and on labour experience, on the relations which were established between people in the process of labour. The labour activity of human society determined the form of the state and left its mark upon the needs of people, their cultural life and views. J. V. Stalin says: "...whatever is the mode of life of people such is their mode of thought." This means that consciousness is the product of the history of society.

Consciousness and the brain. It is impossible to separate consciousness from the activity of the brain. Not a single psychical process can proceed without the work of the brain. Formerly, it was supposed that consciousness depended on some definite sections of the cerebral cortex. Now it is an established fact that consciousness is connected with the activity of the whole cerebral cortex.

The higher nervous activity of man is of an immeasurably greater complexity than that of dogs and of any other animal. However, as the work of Krasnogorsky, Ivanov-Smolensky and other scientists has proved, there are many common features, and not only differences, to be found in the activity of the cerebral cortex of man and of the higher animals. That is why Pavlov's study of conditioned reflexes has contributed very much to the understanding of higher nervous activity in man.

Pavlov's study of the first and second signal systems. In the human being, as in animals, conditioned associations, which are the basis of all higher nervous activity, are formed in the cerebral cortex. "A temporary nervous association is the most universal physiological phenomenon in the animal world and also in ourselves." (Pavlov)

One may observe the formation of conditioned reflexes in an infant from the very first days of its existence. A slight touch on its lips produces sucking movements. This is an unconditioned reflex. If the child is repeatedly fed from a feeding bottle, a conditioned reflex is formed: the sucking movements appear at the sight of the bottle alone. "This," says Pavlov, "is the first signal system of the reality, common to us and to animals." However, this is of secondary importance in the higher nervous activity of man.

Words play a special role in the formation of conditioned associations in the cerebral cortex of the human being. "A word," says Pavlov, "being a signal of the first signals, composed the second signal system — which is so specifically ours — of the actuality." According to Pavlov, the conditioned associations in the cerebral cortex of a human being are formed chiefly by speech stimuli. The essential side of speech is composed, not of separate words or sounds, but of their combinations, which acquire definite sense. In other words, associations are established as a result of the understanding, the perception of speech.

The research work of Ivanov-Smolensky has proved that the first and second signal systems are always so closely connected and interrelated that we may speak of their *unity*. And, indeed, direct impressions received from various objects and phenomena are absolutely connected not only with corresponding words, but also with conceptions which make it possible to comprehend the direct impression.

It is, namely, the second signal system — that is, comprehensive speech, and not separate sounds or words — that forms the basis of human thought. "Whatever the thoughts that may arise in the mind of man and whenever they may arise, they can arise and exist only on the basis of the fabric of the language, on the basis of language terms and phrases." (Stalin.)

The analysis and synthesis of stimulations. Analysis and synthesis of stimulations are far more complete and profound in the human being, in spite of the fact that the separate sense organs are so much less perfected than in animals.

"An eagle," said Engels, "can see considerably further than a human being, but the human eye observes considerably more in things than the eye of the eagle." In comparison with man, the dog possesses a more developed sense of hearing. It can differentiate 1/8 tone, which is absolutely inaccessible to the human ear. But the understanding of human speech is inaccessible to the dog, for it is not capable of analysing speech stimuli.

The profound analysis and synthesis of stimulations that are inherent in man is tied up with the peculiarities in the structure and activity of his brain. And it is namely with the high state of development of the cortex of the cerebral hemispheres that human consciousness is connected.

76. The hygiene of the nervous system

The nervous system and the sensation of tiredness. The working capacity of a person, and also the sensation of vivacity or tiredness, depend, to a great extent, upon the state of the nervous system.

When a person is occupied in doing some physical or mental work, zones of excitation arise in the cerebral cortex. Simultaneously, those parts of the cortex which have no connection with the fulfilment of the given work are inhibited.

The greater the interest of a person in his work, the stronger will be the excitation in some parts of the cerebral cortex, and the deeper the inhibition in others. That is why a person who is deeply engrossed in his work notices nothing that goes on about him: he is not conscious of the presence of people in the same room, nor of what they are saying. In such a case, a person accomplishes much better work, and does it more attentively and much more quickly. Interesting work (connected with strong enough zones of excitation) may be continued for a long time without bringing about any feeling of tiredness.

The will to work is of great importance. The working capacity is always higher if a person turns his whole attention to his work and strives to accomplish it quickly and well. It is not without reason that a person who shows no interest in his work is considered to be a poor worker.

Pavlov proved by his experiments that weak and monotonous stimuli, to which the organism is indifferent, help to spread a state of inhibition in the cerebral cortex. Dull, uninteresting work, fulfilled without any keen desire, has the same effect. As a result, the excitability of the cerebral cortex is lowered, and a feeling of weariness sets in, which, however, diminishes and sometimes completely disappears if an interest is shown in the work.

Fatigue. Work, especially physical work, brings about an active state in the organism; metabolism is intensified, the excitability of all the organs, and especially of the nervous system, is increased. However, gradual changes take place in the chemical composition of the organs and of the tissues, and various products of metabolism accumulate. As a result, the working capacity of the separate organs, as well as of the whole organism, is lowered. This state of the body is called fatigue to differentiate it from the simple feeling of tiredness. However, fatigue does not lead to injurious results, and the changes brought about in the organism by fatigue may completely disappear after a good rest.

A feeling of tiredness, a lowering of the productivity of work, and a growing lack of interest in work, are usually the first stages of developing fatigue, — all this is connected with the gradual strengthening of the processes of inhibition. Work becomes more difficult to perform in proportion as inhibition dominates over excitation.

Pavlov put it aptly when he said that a "*guarding inhibition*" arises in the nerve cells of the cerebral cortex in order to protect the organism against excessive fatigue and exhaustion: this "guarding inhibition" often makes its appearance long before fatigue sets in, sometimes even at the very beginning of work. In such cases, in order to continue to produce fruitful work, one must overcome by force of will the feeling of tiredness connected with inhibition, and increase the excitability of the cerebral cortex. The best method of doing this is to apply oneself *conscientiously* and assiduously to one's work.

Rest. In order that fatigue should not turn into over-fatigue, so harmful to the nervous system and to the whole organism, there must be intervals of rest between work, in order that the strength of the organism and its working capacity may be restored.

After difficult or long-continued work, a person often has an irresistible desire to lie down or to sit quietly for a while.

In cases of intense fatigue, the organism actually needs a complete rest. However, a passive rest is not what is needed in the majority of cases. Rest must help to strengthen the organism, and in order to be able to do this, it is necessary for the organism to be active.

In many cases, a change from one form of activity to another provides sufficient rest. Thus, physical work is a splendid rest after the strain of mental activity. On the other hand, a person fatigued by physical work, derives pleasure in reading a book or in playing a game of chess, and in so doing, rests.

A person should absolutely spend a part of his leisure time in active rest, in the open air. Excursions, walks, ice-skating, skiing, and many games of sport, which strengthen the organism, are types of rest that have no equal as regards the nervous system. Morning setting-up exercises are of especially great importance. They harden the organism and brace a person up and, raising his working capacity, put him in a fit condition for the whole day. Any physical exercises, regularly performed every morning, will have a beneficial effect upon the general state of the organism.

The daily routine. By daily routine is meant the distribution, in the course of the day, of those activities which a person must fulfil. Work, rest, sleep, meals, a walk — all these should always have definite hours. If a regular routine of the day is established, conditioned reflexes to time are easily formed, habits are built up which provide for rhythm in the mode of living. If a person forms the habit of having his meals at regular hours, the secretion of gastric juices begins as the time approaches, an appetite appears and the food is more easily digested.

One concentrates much more quickly and easily, and work "hums" more readily at times fixed by habit.

If a person forms the habit of going to bed and of getting up at a definite time, he will fall asleep quickly at night and awake easily in the morning.

Routine that is strictly adhered to creates those ***conditioned associations*** in the cerebral cortex, which are necessary for habit formation, and provide for rhythm in life, which facilitates the work of the whole organism.

The arrangement of the daily routine should include, first of all, the regular alternation of work and rest; this creates the best conditions for the activity of the brain and of the whole organism, and prevents a person from becoming over-fatigued. Between meals there should be regular intervals corresponding to the work of the digestive organs, and thus facilitating their activity. For the sake of improving the health, enough time must be set aside for taking walks and for the hygienic care of one's body. Finally, the daily routine must include a regular and sufficient amount of sleep.

Sleep and its importance. The normal flow of the life processes is possible only under conditions of periodic alternations of wakefulness and sleep. Sleep restores the strength of the organism. Continued insomnia, or sleeplessness, may cause death in a shorter period of time than the lack of food. As was proved by experiments with dogs, considerable changes take place in the nervous system, and especially in the cerebral cortex, when the animal is deprived of sleep for a long time; such changes finally bring about the destruction of the cells.

Basing himself on the study of the processes that go on in the cerebral cortex, Pavlov explained that sleep is ***an inhibition*** which spreads throughout the cortex and to the lower divisions of the brain.

The appearance of a sufficiently strong zone of excitation in the cerebral cortex, caused, for example, by toothache or stomach-ache, may bring the inhibition to a stop and in that way destroy sleep. And, on the contrary, if everything that prevents inhibition from spreading in the cortex is removed or eliminated (for example, noise, light and other strong stimuli), sleep is more easily induced. When one undresses and covers himself with a blanket, he lessens the flow of impulses from the sense organs, because he removes the irritating action of his clothes and of the cold. The flow of impulses from the muscles, tendons and joints is reduced by the relaxation of the muscles and by lying in a comfortable position.

Those habitual acts which we perform every day before going to bed — brushing the teeth, washing ourselves, arranging the bedding for sleep, undressing, become conditioned stimuli, which cause the process of inhibition to spread in the cortex. Weak, monotonous, indifferent stimuli also facilitate this process, which explains the ease with which we doze off to the rhythmic rocking and clash of the wheels of a moving train, or when reading a dull book. A mother, in lulling her child to sleep, produces exactly the same monotonous flow of impulses, which helps inhibition to spread more quickly through the cerebral cortex.

The speed with which sleep comes is influenced very greatly by the state of the organism, and especially of the cerebral cortex. Fatigue after doing habitual mental and, especially, physical work, induces sleep by lowering the excitability of the brain and by helping inhibition to spread more easily.

Over-fatigue of the brain, caused by extremely strenuous work, worry, agitation, fear, has the reverse effect.

Over-fatigue and excessive excitation are often the cause of insomnia.

The spreading of inhibition lowers the activity of the whole central nervous system; this weakens the muscle tone and lowers metabolism, which, in its turn, brings about a change in the work of the respiratory and circulatory organs: the frequency of the pulse and of the respiratory movements becomes diminished.

Watch-points in the cerebral cortex. In an experiment performed in Pavlov's laboratory, a conditioned salivary reflex to the tone "do" was built up in one of the dogs. Besides this, other sound stimuli were applied, which, however, were never reinforced by giving the animal food. As a result, these sounds not only failed to produce any conditioned reflex, but, on the contrary, they served to bring about the development of the process of inhibition in the cerebral cortex. When the inhibitory tones were repeated many times in succession, the dog fell asleep on the stand. But no sooner was the conditioned stimulus (the tone "do") applied than the dog began to secrete saliva, and sleep was destroyed.

Those sections of the brain which maintain connection with the external world during sleep, Pavlov called the watch-points of the cerebral cortex. These are usually connected with stimuli of especial importance to the animal (in our example it was the food stimulus).

There are similar watch-points also in the cerebral cortex of a human being when asleep. A mother, who dozes off at the bedside of her sick child, does not react to loud claps of thunder, but wakes up at once in response to a slight moan of the child. A soldier, sleeping calmly during a cannonade, wakes up at once when the voice of his commander is heard.

Dreams. During sleep restricted zones of excitation may appear in various parts of the brain; certain movements, and sometimes even jumping up or talking in one's sleep are explained by the presence of these zones.

Dreams are also connected with *zones of excitation,* aroused by impulses which enter the cortex of the cerebral hemispheres from the organs of the body. A change in the position of the body, hunger or thirst, an over-loaded intestinal canal or urinary bladder, a change in the respiratory movements or in the work of the heart, may serve as stimuli producing a flow of impulses. One often has depressing, unpleasant dreams after a too heavy meal, when the abdominal organs press upon the diaphragm, lifting it up and thus making respiration and the work of the heart difficult. If the nose is suddenly freed of mucus, the respiration becomes easier, and one may get a sensation, while asleep, of flying freely in the air.

Dreams are also produced by impulses coming from the sense organs. Experiments, performed with people when they are asleep, have proved that the sound of flowing water from a faucet may result in a dream about a river or a waterfall, while a hot water bag applied to the soles of the feet may cause a dream about a burning desert with sand heated up by the sun.

Very often dreams are connected with phenomena of which we were eye witnesses, or with events about which we heard, read or thought. We may dream about events which were blotted out of the memory long before, or which were unnoticed at the time and failed to reach the consciousness, although they occurred in our presence.

This is explained by the fact that *traces* of all impulses, even of the most insignificant and transient, coming from the sense organs, are retained in the cells of the cerebral cortex.

The content and character of one's dreams are closely connected with the peculiarities of one's cerebral activity, with one's individual impressions, reminiscences, interests, cares.

Even when wide awake, a person's thoughts often jump from one subject to another, and this is especially true when a person is asleep. That is why a person may see the most inconceivable and most senseless things in a dream.

It sometimes happens that a dream coincides with the reality. In such cases, superstitious people and people of little culture speak about "prophetic" dreams. Of course there can be nothing prophetic in such accidental, coincidental dreams.

The hygiene of sleep. In order that the organism should get the rest it needs, and that the forces expended during the day should be fully restored, a person must have a sufficient amount of sleep.

Adults need 8 hours of sleep a day. The normal amount of sleep for children and adolescents depends upon age: the younger the child, the more sleep it needs. School-boys and girls of 14 to 16 years of age should have no less than 9 hours of sleep.

One must have a regular time for going to bed. Sleep in the evening and at night is much deeper and more useful than morning sleep; therefore, it is better to go to bed early and to get up early.

During sleep, nothing should interfere with respiration, with the blood circulation and with the normal work of the skin. Before going to bed, one should take off all the clothing one wears in the daytime, and put on a fresh nightgown. No belts or bands should be worn round the waist, because they interfere with the circulation of the blood. One should lie at full length when sleeping — best of all on one's right side, with the arms on top of the blanket. If one sleeps on the left side, the left half of the thorax is compressed and makes the work of the heart more difficult.

It is very important to breathe fresh air when sleeping. Therefore, it is necessary to air the room well before going to bed. It is still better to leave the window partly open all night, and when the weather is warm, to keep it wide open. On no account should the blanket or sheet be pulled over the head.

The air in the room during sleep should be cool: not over 15 or 16° C. It is not necessary to cover oneself too warmly.

REVIEW QUESTIONS

1. What kind of reflexes are those that are called conditioned, and how do they differ from unconditioned reflexes?
2. How are conditioned reflexes built up?
3. What are the conditions required for the performance of experiments in the study of conditioned reflexes?
4. Of what significance are conditioned reflexes in the life of animals?
5. Under what conditions does inhibition of conditioned reflexes arise, and of what importance is it?
6. How do the processes of excitation and inhibition proceed in the cerebral cortex?
7. What are analysers? Explain the analysis and synthesis of stimulations.
8. What are the specific features of the higher nervous activity of a human being?
9. What are the roles of Setchenov and Pavlov in the development of the study of higher nervous activity in man?
10. How does fatigue arise?
11. What conditions help to raise the working capacity?
12. How must one organize one's rest?
13. Of what importance is it to the organism to follow a regular routine?
14. Why is sleep important? How did Pavlov explain the phenomenon of sleep?
15. Enumerate the chief rules of the hygiene of sleep.

XI. PHYSIOLOGICAL PECULIARITIES OF THE GROWING ORGANISM

77. Fertilization

The sex cells. The sex glands may be considered to be mixed glands, because they possess the property of secreting both internally and externally. The external secretion of the sex glands consists in the formation and elimination of sex cells.

The female sex cell, or *ovum*, develops in the female sex gland — the ovary. The male sex cells, or *spermatozoa*, are developed in the male sex glands — the testes.

The ovum, or egg cell. The matured ovum, like any other living cell, consists of *a nucleus* and of *protoplasm* (Fig. 139). The protoplasm of the ovum is called *embryonic protoplasm*; it contains a store of material upon which the developing embryo is nourished. The ovums of a human being and of mammals hold an amount of nutritive material sufficient only for the initial stage in the development of the embryo, because later it receives the nutritive material necessary for its development direct from its mother. This accounts for the small size of the egg cells in mammals. The human ovum is only 0,1 or 0,2 *mm.* in diameter.

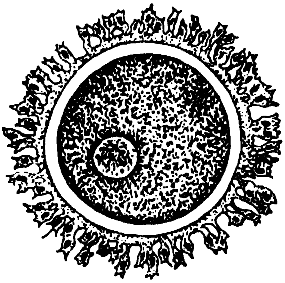

Fig. 139. Human ovum surrounded by the embryonic membrane.

The nucleus is seen inside. The protoplasm of the ovum contains granules of nutritive material.

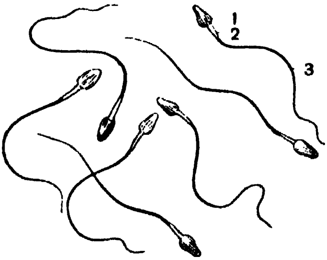

Fig. 140. Spermatozoa.

1 — head; *2* — middle piece; *3* — tail.

Spermatozoa. The spermatozoa are incomparably smaller than the egg cells. The spermatozoon is a minute cell, visible only under the microscope (Fig. 140). The thickened part — *the head* — contains *the nucleus* of the cell; the long part, which is called *the tail*, consists of *protoplasm*. Spermatozoa are very *motile*; they move about by means of the lashing movements of their tails. In spite of their microscopically small size, they may traverse a great distance — great in comparison with their size — about 25 *cm.* an hour.

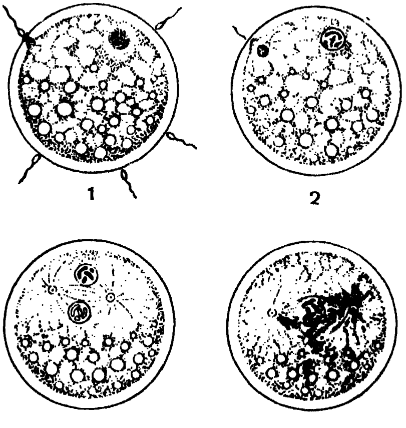

Fig. 141. Diagram of the fusion of a male and a female cell during fertilization.

Fertilization. The development of the embryo begins at the moment of fertilization, that is, at the moment the male sex cell, or spermatozoon, has penetrated the female sex cell, or ovum (Fig. 141). As a result of the fusion of the two sex cells, a new cell is formed, which differs in quality from both the ovum and the spermatozoon. Such a fusion of cells provides for the transmission of traits from both parents to the new organism.

The organ in which the fertilized cell undergoes further development is called *the uterus.*

78. Development within the uterus

The development of the embryo. The fertilized egg cell begins to develop rapidly, and is soon transformed into a multi-cellular embryo, the number of cells of which keeps on increasing continually. Three embryonic layers appear: the outer (ectoderm), the inner (endoderm) and the middle layer (mesoderm). During the further development of these layers, the rudiments of the separate organs begin to appear.

Nutrition of the embryo. Membranes begin to form at once round the embryo even during the initial stage of its development; one of these membranes (the outer one) is called *the villous membrane,* because it is completely covered with little projections, like the pile of velvet. With the help of the villous membrane, the embryo attaches itself to the mucous coat of the uterus (Fig. 142), which, by this time, has swelled out and has become, as it were, slack. The villi become firmly imbedded in the mucous coat, fusing with it, and thus forming *the after-birth,* or *placenta.*

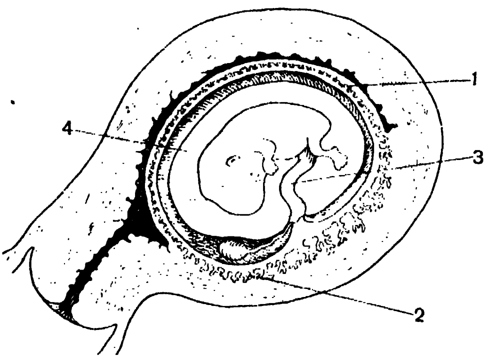

Fig. 142. Human embryo in the uterus:
1 — villous membrane; 2 — placenta; 3 — umbilical cord; 4 — amniotic fluid.

By means of the placenta, an interconnection is established between the foetus and the maternal organism. A cord — *the umbilical cord* — extends from the body of the embryo to the placenta. Within the umbilical cord there are blood vessels. The contractions of the heart of the embryo force the blood along the arteries of the umbilical cord to the placenta, where metabolism of the maternal blood and the embryonic blood takes place; in this way the blood of the embryo is freed of the products of exchange and becomes rich in oxygen and nutritive material. The arterial blood returns to the organism of the embryo through a wide vein (Fig. 143).

The similarity in the development of the human embryo and the embryo of animals. The embryo does not take on the semblance of a human being at once. In the early stages of development, the embryos of the human being, the monkey, rabbit, hen, and even the fish, resemble each other very much (Fig. 144). In the third week of the development of the human embryo, folds appear on either side of the anterior end of the body; such folds likewise appear in the early stage of the embryonic development of all vertebral animals. These are rudimentary *gills*, which, in fish, develop into real gills; in animals that live on land, the rudimentary gills disappear later without leaving any trace.

In various periods of the life of the embryo within the uterus, other special features, not characteristic of the human being, also appear, but are not retained in the later stage of development. Thus, at one stage of its development the human embryo has *a tail*, which remains for rather a long time. At another — later — stage, the whole body, and even the face, is *covered with fine hairs* for a short period of time.

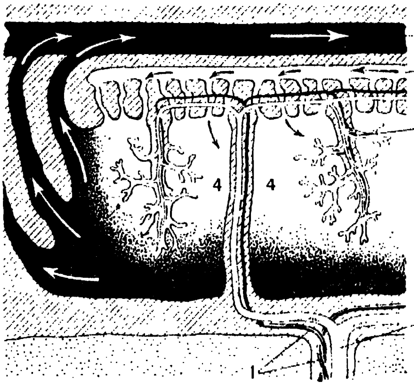

Fig. 143. Diagram showing the movement of embryonic blood and of maternal blood in a small section of the placenta:

1 — umbilical arteries; *2* — umbilical vein; *3* — villi enclosed in a space filled with maternal blood (*4*); the maternal blood flows in through the arteries (*5*) and out through the veins (*6*).

The *cartilaginous* skeleton that appears in the fifth week of embryonic development, and is later transformed into the bones of the skeleton, is also not characteristic of the human being.

Unity in the animal world. The simplest organisms that ever existed on the earth went through stages of gradual development and were transformend into new organized forms of ever increasing complexity. Many millions of years passed before such varied and dissimilar species of animals and plants, which are found in the world to-day, made their appearance. But just as the branches of a tree have their origin in one common stem, so also all living creatures, no matter how much they may differ from one another, arose from one common life stem: they are the numerous branches of a single tree of life.

The science of embryological development — embryology — proves that all organisms, in their transformation from the egg cell to the adult stage, show traces, as it were, of a time long past, and tend to repeat the separate stages in the history of the development of their ancestors.

There is no doubt that the rudimentary gills, found in the embryos of all vertebrates including man, prove that at a certain stage in the development of life, the common ancestors of all vertebrates lived in the water and, like fish, breathed through gills.

It is true that the embryo, in the course of its development, reflects only the most basic features in the organization of its ancestors; but these features, nevertheless, give us an idea of the path of the development and origin of man.

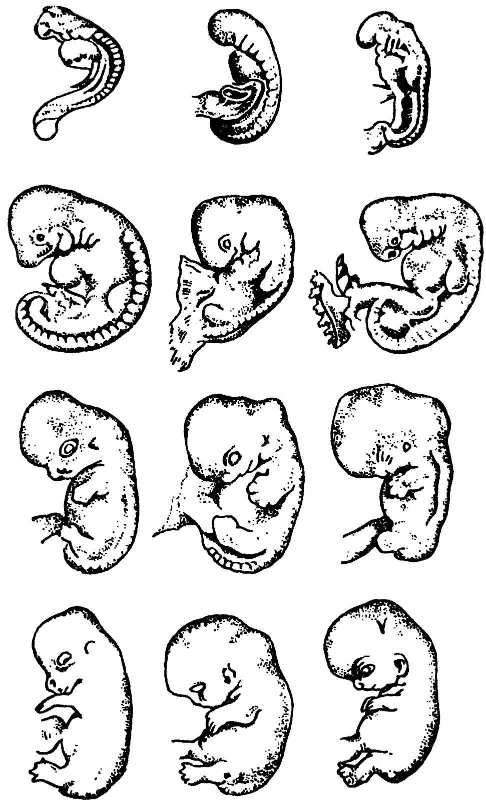

Fig. 144. Early stages in the development of the embryo of a guinea pig (on the left), of a monkey (in the middle) and of a human being (on the right.)

In each of the vertical rows are shown the successive stages in the development of the three embryos respectively.

The further development of the foetus. At the end of the second month of embryonic development, the rudimentary gills disappear and points of ossification — the first islets of bony tissue, appear in various parts of the cartilaginous skeleton. By that time the differentiation between arms and legs becomes noticeable, and the whole body of the embryo acquires characteristic human features; at this stage of development the embryo is called *the foetus*. The foetus lies in the membranes enclosing it as if in a spacious bag. *The amniotic fluid*, which is inside the bag (Fig. 142), gives the foetus freedom to develop and also the possibility to move about. Moreover, it serves as a good buffer to receive the first shocks of any accidental jolts or knocks which the mother may get. The foetus grows and develops rapidly, so that at the time of birth it may be about 50 *cm.* long and may weigh about 3 *kil.*

In the course of the nine months of its life in the uterus, the embryo does not inhale air, nor does it digest food. All this is done for it by the mother. Therefore, if the kidneys, which remove unnecessary and harmful substances from the blood, do not work well in a pregnant woman, and if she does not take enough nourishing food, or if she does too strenuous work which over-fatigues her organism — all this will tell immediately upon the development and health of the embryo. That is why the concern shown for the health of a pregnant woman provides, at the same time, for the health of the future child.

79. Special features in the development of a child and of an adolescent

A new-born child. From the very first moment of its birth, the organism of an infant comes into direct contact with the external environment: it breathes, eats, eliminates waste products. Once the connection with the organism of its mother is cut off, the child immediately begins to accumulate, in its blood, carbonic acid, which was formerly eliminated through the placenta. The accumulated carbonic acid irritates the respiratory centre and, as a result, the inspiratory and expiratory muscles begin their alternate contractions. The so-called *first cry* of the child is an indication that respiratory movements have begun.

Together with the first cry come changes in the circulation of the blood. Before birth, when the lungs are in a collapsed state, only a very small amount of blood passes through them. The main stream of blood from the right half of the heart flows, not into the lungs, but directly into the left half of the heart through an opening which, in the foetus, is found between the right and left auricles, or into the aorta by means of a special duct that unites the aorta with the pulmonary artery. The inflation of the lungs, caused by respiration, forces the pulmonary vessels to dilate, and thus the free movement of the blood along the small, or pulmonary, circuit of the circulatory system is provided for.

The opening between the auricles and the duct, connecting the pulmonary artery with the aorta, gradually fuses together and closes up; the continuous flow of the whole blood stream is established, finally, through ***both circuits of the circulatory system*** — the systemic and the pulmonary circuits.

Growth and metabolism. At birth an infant weighs approximately 3 ***kil.*** and by the end of the first year — about 10 ***kil.*** It is clear that, with such rapid growth, metabolism in an infant must be very ***intensive.*** And, indeed, an infant expends, for every kilogram of its weight, three times more energy than an adult person.

The intensity with which metabolism goes on demands a greater supply of nutritive material and of oxygen. As a result, the organs of respiration and of circulation have a great amount of work to perform.

Respiration. A new-born infant cannot inspire deeply, and the necessary ventilation of the lungs is accomplished by an increase in *the frequency* of respirations. The number of inspirations per minute during the first few weeks of its life is about 60. Later, the respiratory movements become less frequent in proportion as the thorax grows larger and the muscles of the thorax become stronger.

The work of the heart. The frequency of the heart-beats of a new-born infant is about *twice* that of an adult person, because the heart muscle of an infant is weak and the blood vessels do not possess sufficient elasticity.

Both the pulse and the respiratory movements of a new-born child differ from those of an adult, not only in their frequency, but also in the irregularity of their *rhythm*, which *changes* often. This is due to the fact that the nervous regulation of the organs of circulation and of respiration is not stable enough.

As the child grows, the heart becomes larger in size and the heart muscle becomes thicker and stronger.

However, an excessive and prolonged physical load may lead to emaciation of the heart muscle. For this reason, one must be very careful not to overload with physical work, not only a small child, but a young boy or girl as well, in order to avoid enlargement of the heart and to prevent any disorders in the work of the heart.

Nutrition. The food of the growing organism should contain a sufficient quantity of nutritive material necessary both for the normal work of the body organs and for their growth. The more intensive the growth, the more proteins and fats the food should contain. Proteins are especially important, as they constitute the chief material for the building up of new cells.

Vitamins are very important for the normal nutrition of the growing organism. An insufficient amount of some vitamins retards the growth and interferes with normal development. Besides those vitamins already known to us, vitamin D, soluble in fats, is absolutely necessary for the organism of a child. Vitamin D is contained in cod-liver oil, the yolk of egg, butter and other foods.

In certain fats and in many plant foods there is a substance, soluble in fats, that is related to vitamin D. This substance is stored in the skin, and when acted upon by the rays of the sun, is partially converted into vitamin D.

By exposing the skin to the action of the sun, one increases the supply of vitamin D in the organism. For this reason, it is especially important for children to be out in the sun.

An insufficient quantity of this vitamin in food, or the complete lack of it, destroys the metabolism of minerals, and the content, especially, of calcium and phosphorus in the bones is reduced, which causes the bones to soften, the teeth to decay, and a number of other disorders. In the early period of a child's growth (especially before it is a year old), the lack of vitamin D in the food is the cause of rickets.

In the first few months of its life, a suckling infant is fed exclusively with *maternal milk*, the constituents of which fully comply with the requirements of the child and provide it with the necessary amount of proteins, fats, carbo-hydrates, salts and vitamins.The milk contains anti-bodies which safeguard the organism of the child from the harmful action of various microbes. As a result, children fed with maternal milk are less liable to contract many contagious diseases.

In five or six months after birth, the nutrition received exclusively by suckling proves to be insufficient, and the mother begins gradually to *feed* the child with farina, mashed carrots, cranberry jelly and other food; by the time the child is 12 months old, suckling is completely stopped.

Before the child is two years old, its food becomes as *varied* as that of an adult person: the child may get soup, curds, finely chopped meat, boiled fish, all kinds of porridge and gruel, vegetables and fruit.

Taking into consideration the insufficient stability of the nervous regulation of the heart in children, even older children should avoid the use of stimulating drinks — wine, strong tea or coffee.

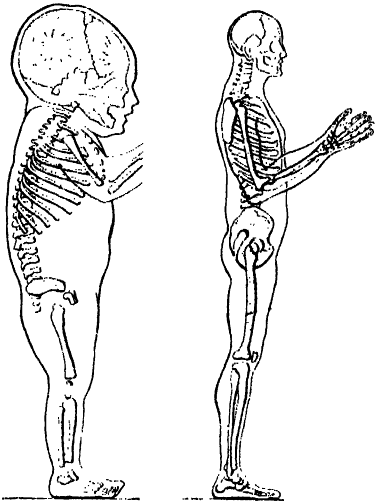

Fig. 145. Skeleton of a new-born child and that of an adult.

The bony-muscular system. The bones of the skeleton develop slowly and gradually (Fig. 145).

At birth, the central part of most of the long bones consists of bony tissue, but the ends of the bones remain *cartilaginous* for a long time. Thus, the first islet of ossification appears in the lower end of the humerus only in the third year of the child's life.

The ossification of the skeleton is completed at about the age of 25.

The skeletal muscles of an infant are *very poorly* developed and are not capable of making prolonged contractions.

The strength of the muscles increases gradually, and the movements become more and more coordinated. At the age of 6 or 7, the child has a sufficiently free control of its muscles and can easily learn to perform many gymnastic exercises, which require ability in balancing the body. However, long and intense strain of the muscles is still very difficult for a child.

School age marks the beginning of a period of ***intense growth*** of the muscles. At the age of 6, the skeletal muscles make up about 22% of the weight of the body; but by the time the boy or girl is 16, these muscles compose 35% to 40% of the weight, the same as in adults.

Boys and girls of the age of 12 to 15 are capable of performing the most ***varied kind of work,*** no matter how complex and fine the coordination of the movements required by such work may be. However, even if the muscles are well developed and strong, too prolonged and too intensive a strain should be avoided at that age, as it may injure the work of the heart.

Each muscle pulls the bone to which it is attached in a definite direction, and thus exerts an influence on the development and growth of the bone, and on the position of the bone slats. The higher the muscle tone and the greater the power of the muscle contractions, the greater will be the influence exerted upon the development of the bone. Therefore, the growth of the muscles and the increase in their activity ***accelerate the development of the skeleton and harden it.***

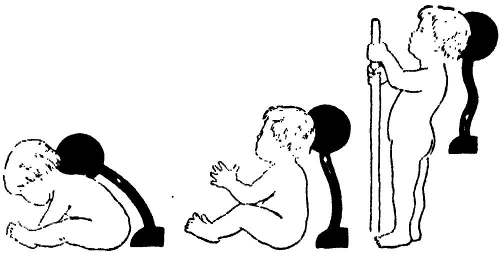

Fig. 146. Curves of the spinal column that are formed in sitting and standing.

Consequently, plenty of motion is a necessity for a child and for an adolescent in order that the muscles, as well as the skeleton, should develop normally. Setting up exercises, games of sport, walking excursions, develop the muscles, and at the same time develop and harden the whole organism.

The appearance of curves in the spinal column. There are ***hardly any curves*** in the spinal column of a new-born child. As a result of the increased tension (tone) of the muscles of the neck, the child, at 2 or $2^1/_2$ months, begins to lift up its head and then to hold it up. The constant pull upon the muscles at the back of the neck, which prevents the child from dropping its head forward, gives rise to ***a curve,*** or arch, in the spinal column at ***the neck.***

Somewhat later, when the child is able to sit up, a second curve appears — ***the thoracic curve;*** when the next step is reached — the upright position of the trunk of the body (standing or walking), ***the lumbar curve*** is developed (Fig. 146).

However, the curves of the spinal column easily change in the course of time, — depending upon the posture of the body. Thus, a bent-over position will greatly intensify the thoracic curve and diminish the lumbar curve. If the carriage of the body is such that the trunk is inclined to one side, a side curve will appear. Frequent and prolonged maintenance of the body in an incorrect posture will produce habitual abnormal curves of the spinal column, which will gradually become more and more fixed, and turn into a diseased condition — curvature of the spine.

At school age, and especially after the age of 10 or 12, when rapid ossification of the skeleton is going on, a curvature of the spine that has developed cannot be corrected and has a bad effect upon the general physical development, the work of the organs of respiration and even on the working capacity.

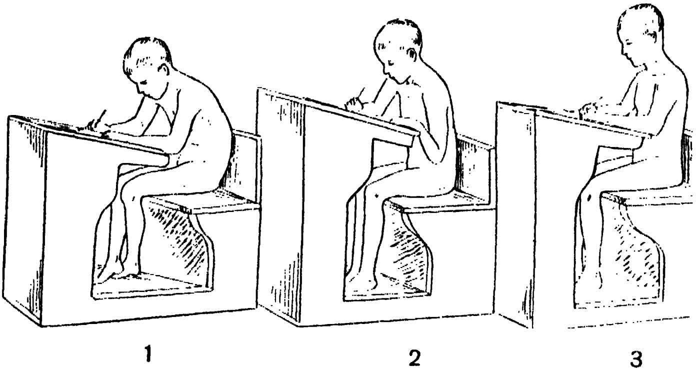

Fig. 147. Incorrect and correct posture when sitting at a desk:

1 — incorrect posture of the body when the desk is too low; *2* — incorrect posture when the desk is too high; *3* — correct posture when the desk is of the right height.

For this reason it is very important to pay attention to correct posture while working. Figure 147 shows the correct posture when sitting at a desk. It is not less important to maintain good posture when standing and walking.

The nervous system. The nervous system absolutely takes part in all of the processes that go on in the organism. The coordinated reactions of the whole organism, as well as the work of each separate organ, depends upon the degree of development of the nervous system. There is, therefore, nothing strange in the fact that, at the moment of birth, the nervous system is already *formed* to a considerable extent.

The weight of the brain of an adult person is about 2% of the weight of the body, but in a new-born child it composes 12% to 14% of the weight of its body (Fig. 148). By the time the child almost reaches school age, the weight of the brain is not less than 80% of the weight of the brain of an adult.

The development of the brain corresponds to the growth of the skull. The height of the head of an adult person is $^1/_8$ of the height of the whole body, but in the new-born child it is $^1/_4$ (Fig. 149).

Evidently, new nerve cells can be formed only in the period of development within the uterus. In other words, the size of the brain increases after birth as a result of *the growth* of the nerve cells, and not because the number of nerve cells increases. The tree-like projections (dendrites) grow especially fast.

In a new-born child, the cortex of the cerebral hemispheres functions very weakly, although conditioned associations may already be formed. Gradually, the movements become not only more varied, but more expedient, in proportion as the corresponding parts of the brain develop. This shows that the cerebral cortex takes an ever increasing part in motor reactions.

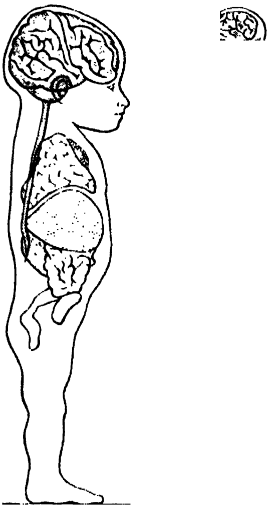

Fig. 148. Size of the brain in relation to the height of a new-born child and of an adult.

The building up of *conditioned reactions,* chiefly food reactions, begins in the first few weeks of a child's life. Very soon defence conditioned reflexes appear: the child cries, and jerks away its arm when only one signal of an unconditioned stimulus is used, for example, if somebody threatens to strike it on the hand. By the end of the first year, conditioned associations with *speech* stimuli have been formed in the cerebral cortex.

The development of the cortex of the cerebral hemispheres (the growth of the nerve cells and their projections) continues in the course of many, many years. *The associations* between the various cells of the cerebral cortex increase in number and in complexity from year to year. In proportion as the associations increase, the higher nervous activity of the child increases in complexity. However, up to adolescence, the cells of the cerebral cortex still have a tendency to become quickly exhausted and to break down.

The processes of excitation and of inhibition *irradiate rather easily* in the cerebral cortex of a child and of an adolescent. This accounts for the lower degree of concentrative attention peculiar to children.

In order that the development of the nervous system, especially of its higher division — the cortex of the cerebral hemispheres — should proceed normally, it is of the greatest importance to observe the basic rules of hygiene and, particularly, to organize a regular daily regimen.

The endocrine glands. The role of the separate endocrine glands *differs* at various periods in one's life. Thus, for example, in the first few years of a child's life, the thymus gland, located in the thorax, behind the sternum, is of vital importance for normal growth and development. Later, this gland lags behind in growth; by the time the child is 12 or 15, the gland is much reduced in size; besides, the glandular tissue is replaced, to a considerable extent, by fatty tissue.

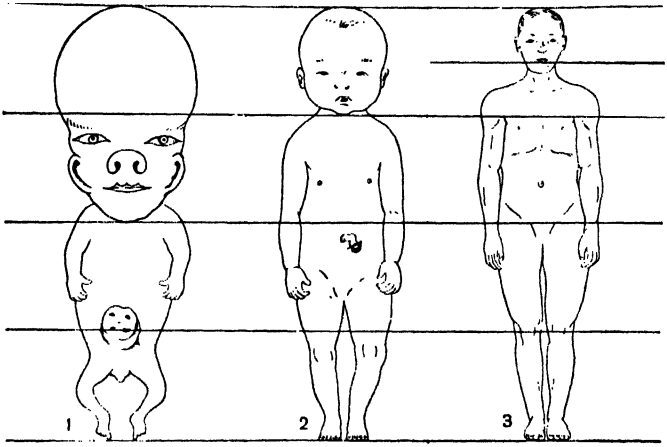

Fig. 149. Changes in the proportions of the body during the process of development:

1 — embryo of two months; *2* — a new-born child; *3* — an adult.

The sex glands develop very rapidly between the ages of 12 to 15, and their hormones bring about profound changes in the activity of the whole organism. These changes are not limited to the appearance of the secondary sexual characters. General changes in the activity of the whole organism, including the cerebral cortex, take place side by side with changes in the voice, the appearance of a hairy growth on the face of the male, changes in the shape of the body. In this transitional stage of growth, adolescent boys and girls lose some of that activity and love of mischief which are so characteristic of pupils of the first classes at school. The attention becomes more concentrated and steady. Perseverance appears.

80. Safeguarding the health of children and of adolescents

Infant and maternity welfare. There is not one country in the world that can compare with the U.S.S.R. in the measures taken to safeguard the health of the rising generation.

Soviet laws take care of the child from the very moment it begins its life in the uterus. Pregnant women who work get a leave before and after giving birth, and are compensated for their work-time. During pregnancy and after giving birth, a woman may have the advice of special physicians, free of charge, as to the care of her own health and that of her infant. There are special consultations for that purpose. A woman may leave her child in a public nursery while she is working. A mother receives a sum of money at the birth of the third child. At the birth of the fourth child (and of any subsequent children), the state pays the mother a monthly compensation for five years running.

All these measures for infant and maternity welfare have brought about a sharp decline in the death-rate of children. Thus, for example, the death-rate of infants in Moscow is just about half of what it was before the Great October Socialist Revolution.

Sanatory measures. There is a whole system of sanatory institutions in the Soviet Union which are at the service of children and adolescents: sanatoriums, sanatory and open-air schools, sanatory camps for young pioneers, sanatory summer playgrounds and colonies.

All public nurseries, kindergartens, schools and other institutions, in which healthy children may be found, are under constant supervision and inspection by special physicians. Breakfasts are given at schools.

Safeguarding juvenile labour. By taking power into its own hands, the proletariat completely liquidated the exploitation of any kind of labour, including child labour. Young boys and girls may get into a factory or shop through an industrial school, where they are taught to become skilled workers of a trade or profession of their own choosing.

The participation of juveniles in industrial work is so regulated that the work does not affect their health, and serves only as a means for the correct and all-round development and hardening of the organism. Juveniles are not given any specially injurious or strenuous work to perform.

All juveniles working at factories undergo a medical examination once a year, on the basis of which necessary sanatory measures are taken for those in need of them.

Juvenile workers receive additional vacation, and are sent to houses of rest, sanatoriums, health resorts.

REVIEW QUESTIONS

1. What are the female and male sex cells called, and what is their structure?
2. Describe the process of fertilization.
3. Describe the development of the embryo and of the foetus within the uterus.
4. What points of similarity are there in the development of the embryo of a human being and that of an animal? What does that prove?
5. What are the specific features of development in a child and in an adolescent?
6. Of what importance is vitamin D?
7. What important factors should be remembered in regard to the nourishment of the growing organism?
8. How is the health of children and of adolescents safeguarded in the Soviet Union?

APPENDIX

1. COMPOSITION OF THE MOST IMPORTANT FOODS

No.	Name of the food	Per cent			Number of calories in 100 *gr.* or food
		Pro-teins	Fats	Carbo-hy-drates	
		3	4	5	6
1	Sunflower oil and other kinds of vegetable oils	–	97	–	880
2	Wheat flour	10	0,5	72	335
3	Wheat bread	6	0,4	50	230
4	Rye flour	8	0,5	75	335
5	Rye bread	4	0,2	48	210
6	Rice (polished)	7	0,5	76	336
7	Buckwheat	9	1	70	330
8	Millet	13	0,8	65	320
9	Farina (semolina)	8	—	75	332
10	Pearl-barley	9	2	68	326
11	Barley	11	2	65	322
12	Corn (maize)	10	0,6	66	310
13	Oatmeal	12	6	65	360
14	Macaroni, noodles	11	0,3	70	327
15	Peas	16	0,5	45	250
16	Lentils	18	0,5	45	260
17	Beans	24	2	48	305
18	Soya beans	32	16	29	390
19	Potatoes	2	—	20	88
20	Beets	1	—	14	60
21	Carrots	1	0,2	9	42
22	Sorrel	2	0,4	3	24
23	Cabbage, fresh	3	0,5	9	52
24	Sauerkraut	1	0,2	4	22
25	Tomatoes	0,7	—	3	16
26	Pumpkin	1	—	5	25
27	Vegetables, dried	12	1,5	45	242
28	Vegetables, tinned;				
	a) eggplant	1,5	12	5	135
	b) squash	1,5	6	8	92
	c) stuffed eggplant and peppers	1,3	5	8	82
29	Mushrooms, fresh	3	0,3	4	30
30	Mushrooms, dried	25	2	30	238
31	Apples, pears	0,4	—	13	54
32	Cherries	1	—	13	56
33	Grapes	0,6	—	18	75
34	Raspberries, currants, strawberries	1	—	8	36
35	Raisins	2	0,3	62	260
36	Jam and jelly made of berries, (on an average)	0,4	—	60	245
37	Nuts	15	60	7	630
38	Lump sugar	—	—	100	400
39	Honey	0,3	—	80	321
40	Chocolate	5	20	65	460
41	Cocoa	22	20	20	350
42	Beef, (on an average)	19	8	—	150
43	Veal „	19	5	—	120

Continuation

No.	Name of the food	Per cent			Number of calories in 100 *gr.* of food
		Proteins	Fats	Carbo-hydrates	
1	2	3	4	5	6
44	Pork, (on an average)	16	20	—	245
45	Mutton „	17	16	—	215
46	Ham „	24	20	—	275
47	Sausage (bologna), boiled	20	15	4	230
48	Sausage, smoked	17	14	—	195
49	Sausages (frankfurters)	14	13	1	180
50	Liver, (calf, sheep, ox)	18	3	3	111
51	Chicken, meat, fat	18	9	—	155
52	Goose meat, (on an average)	16	30	—	335
53	Lard	—	99	—	891
54	Tinned meat, stewed	18	12	1	185
55	Sturgeon, Caspian roach, bream, carp	17	5	—	115
56	Pike-perch, pike	18	0,3	—	75
57	Herring, salted	19	13	1	200
58	Caspian roach, dried	45	10	—	270
59	Caviar	30	14	2	254
60	Cod liver oil	—	99	—	891
61	Fish in tomato sauce, tinned	12	6	1	106
62	Eggs, chicken	14	11	0,4	157
63	Cow's milk, whole	3,5	3,5	5	66
64	Sour cream	4	30	3	300
65	Curds	20	5	2	133
66	Cream-cheese	15	40	1	425
67	Cheese with a high fat content (Russian-Swiss)	23	25	3	330
68	Cheese with a low fat content (Dutch cheese)	35	4	2	185
69	Butter	0,5	80	0,5	730
70	Butter, boiled	—	97	—	880

2. VITAMIN CONTENT IN THE MOST IMPORTANT FOODS

No.	Names of the foods	Vitamins		
		A[1]	B	C
1	2	3	4	5
1	Vegetable oils	0	0	0
2	Wheat flour, fine	0	0	0
3	Wheat flour, coarse	0	+++	0
4	Wheat bread	0	+	0
5	Flour from whole grain	0	++	0

---

[1] The content of yellow pigment (near vitamin A) is shown in plant foods.

No.	Names of the foods	Vitamins		
		A[1]	B	C
1	2	3	4	5
6	Rye bread	0	++	0
7	Millet, farina (semolina), pearl-barley	0	0	0
8	Buckwheat	0	+++	0
9	Oatmeal	0	++	0
10	Rice, whole	0	+++	0
11	Rice, polished	0	0	0
12	Corn (maize)	++	++	0
13	Soya beans	++	+++	0
14	Peas	+	+++	0
15	Pods of peas and beans	++	++	++++
16	Green peas	+++	++	++
17	Lentils	0	++	+
18	Potatoes, boiled 15 minutes	0	++	++
19	Potatoes, boiled one hour	0	++	+
20	Beets	0	++	++
21	Carrots	++++	++	+
22	Carrots, boiled	++	+	+
23	French turnips	0	+	+++
24	Turnips	+	++	++
25	Tomatoes, red	+++	++	+++
26	Radishes	0	+	++
27	Lettuce, dark green	+++	++	+++
28	Lettuce, light green	0	++	++
29	Sorrel, spinach	++++	+	+++
30	Scallions	++++	++	+++
31	Onions	0	++	++
32	Cucumbers	0	++	+
33	Cabbage, raw	+++	++	+++
34	Cabbage, boiled	++	++	+
35	Sauerkraut	0	+	+
36	Cauliflower, boiled	+	++	++
37	Apples	+	+	+
38	Pears	0	++	+
39	Apricots	+++	++	+
40	Tangerines, oranges, lemons	++	+	+++
41	Water-melon	0	+	+
42	Melon	+	+	++
43	Grapes	0	++	+
44	Raisins	+	++	0
45	Cherries	++	+	++
46	Gooseberries	+	+	+++
47	Prunes	+++	+	0
48	Raspberries, strawberries	++	0	+++
49	Currants, black	++	+	++++
50	Berries of the dried briar, berries of the mountain ash	++++	?	++++
51	Nuts	+	+++	0
52	Mushrooms	+	++	0

---

[1] The content of yellow pigment (near vitamin A) is shown in plant foods.

Continuation

No.	Names of the foods	Vitamins		
		A[1]	B	C
1	2	3	4	5
53	Barm	+	++++	0
54	Fir and pine needles	++++	?	+++
55	Different kinds of meat and poultry . .	+	++	+
56	Meat, tinned	0	+	0
57	Liver, kidneys	++++	+++	++
58	Fish, fresh	+	+	?
59	Fish, salted or tinned	0	+	+
60	Eggs, chicken	+++	++	0
61	Cow's milk in summer	++	+	+
62	Cheese with a high fat content	++	+	0
63	Curds	0	0	0
64	Butter (in summer when cows graze in the fields)	+++	+	0
65	Butter (in winter)	++	+	0
66	Cod liver oil	++++	0	0
67	Beef fat	++	0	0
68	Pork fat	0	0	0

Symbols for table 2

0 — absence of or very small vitamin content;
+ — small vitamin content;
++ — sufficient vitamin content;
+++ — large vitamin content;
++++ — very large vitamin content;
? — vitamin content unknown.

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[1] The content of yellow pigment (near vitamin A) is shown in plant foods.

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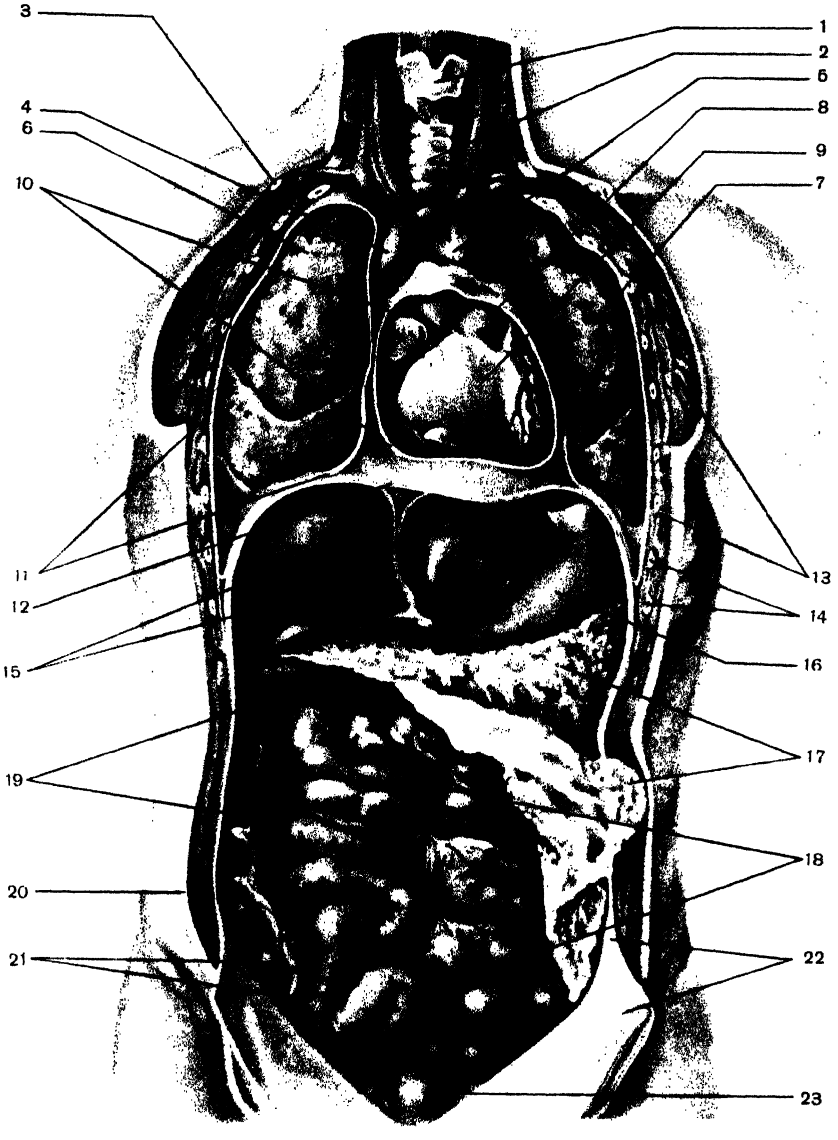

Таблица I. Расположение внутренних органов:

1 — гортань; *2* — трахея; *3* — ключица (поперечный разрез); *4* — верхняя полая вена; *5* — аорта; *6* — правое лёгкое; *7* — левое лёгкое (оттянуто в сторону, чтобы обнажить сердце); *8* — лёгочная артерия; *9* — сердце; *10* — околосердечная сумка; *11* — плевра; *12* — диафрагма; *13* — мышцы (в разрезе); *14* — рёбра (в разрезе); *15* — печень; *16* — желудок; *17* — сальник; *18* — тонкие кишки; *19* — толстые кишки; *20* — кожа и подкожная клетчатка (в разрезе); *21* — слепая кишка с червеобразным отростком; *22* — брюшина; *23* — мочевой пузырь.

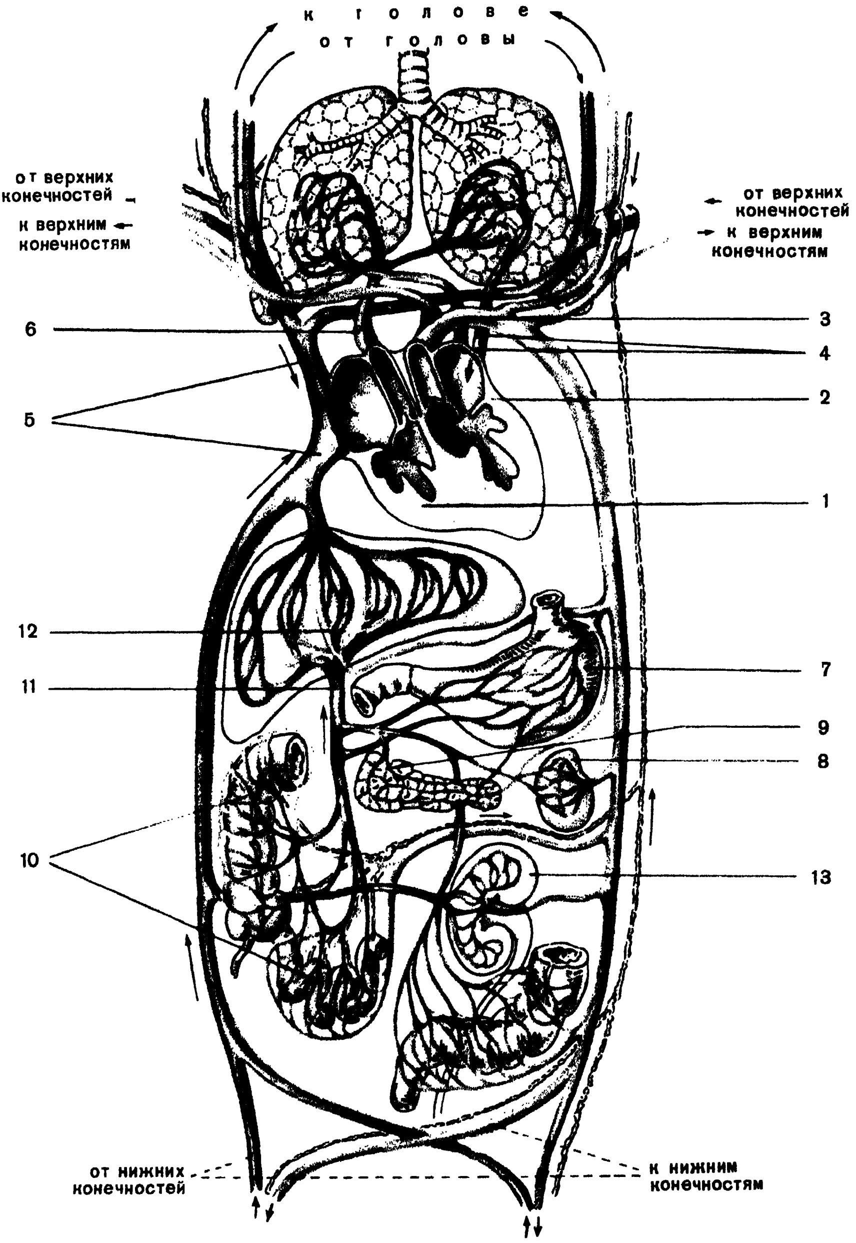

Таблица II. Схема кровообращения и лимфообращения:

Красным цветом обозначены сосуды, по которым течёт артериальная кровь; синим — сосуды с венозной кровью; лиловым цветом показана система воротной вены; жёлтым — лимфатические сосуды: *1* — правая половина сердца; *2* — левая половина сердца; *3* — аорта; *4* — лёгочные вены; *5* — верхняя и нижняя полые вены; *6* — лёгочная артерия; *7* — желудок; *8* — селезёнка; *9* — поджелудочная железа; *10* — кишки; *11* — воротная вена; *12* — печень; *13* — почка.

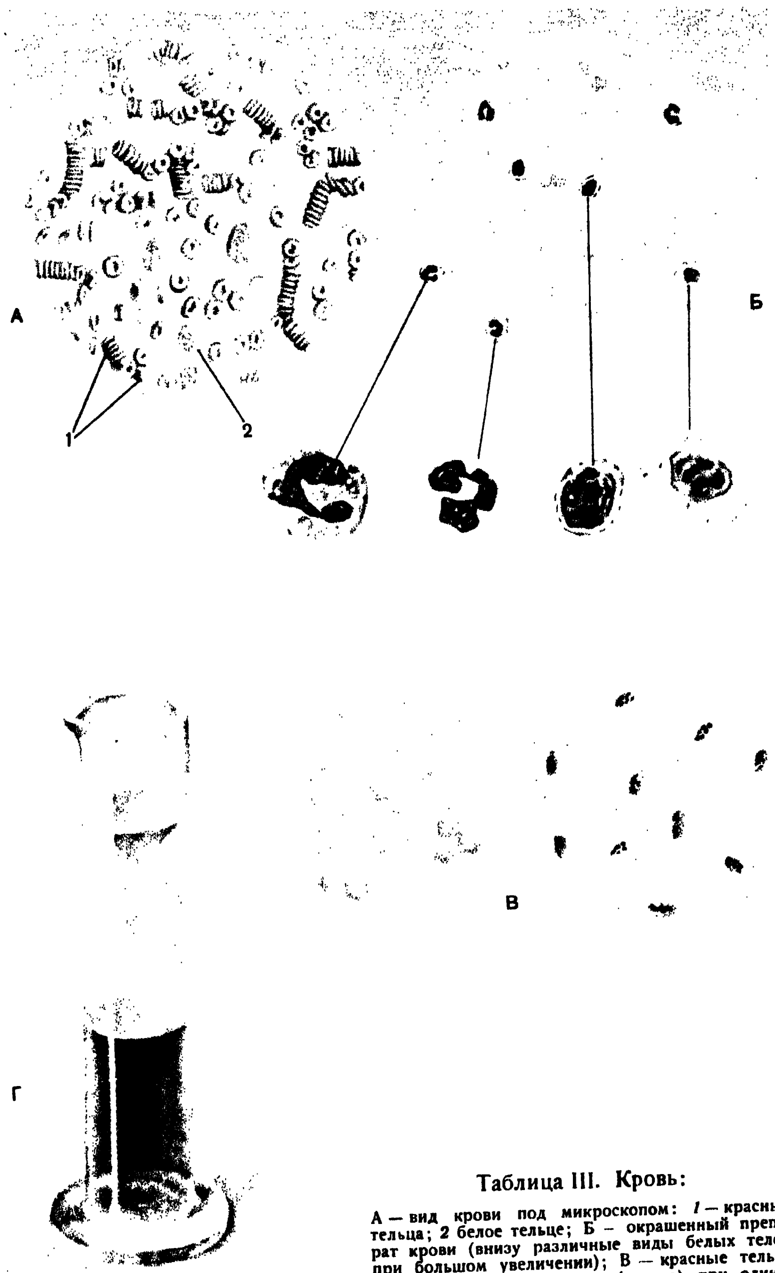

Таблица III. Кровь:

А — вид крови под микроскопом: *1* — красные тельца; 2 белое тельце; Б — окрашенный препарат крови (внизу различные виды белых телец при большом увеличении); В — красные тельца человека (слева) и лягушки (справа) при одинаковом увеличении; Г — кровь, предохранённая от свёртывания, после длительного отстаивания; между верхним слоем (плазмой) и нижним слоем (красными тельцами) виден тонкий беловатый слой белых телец.

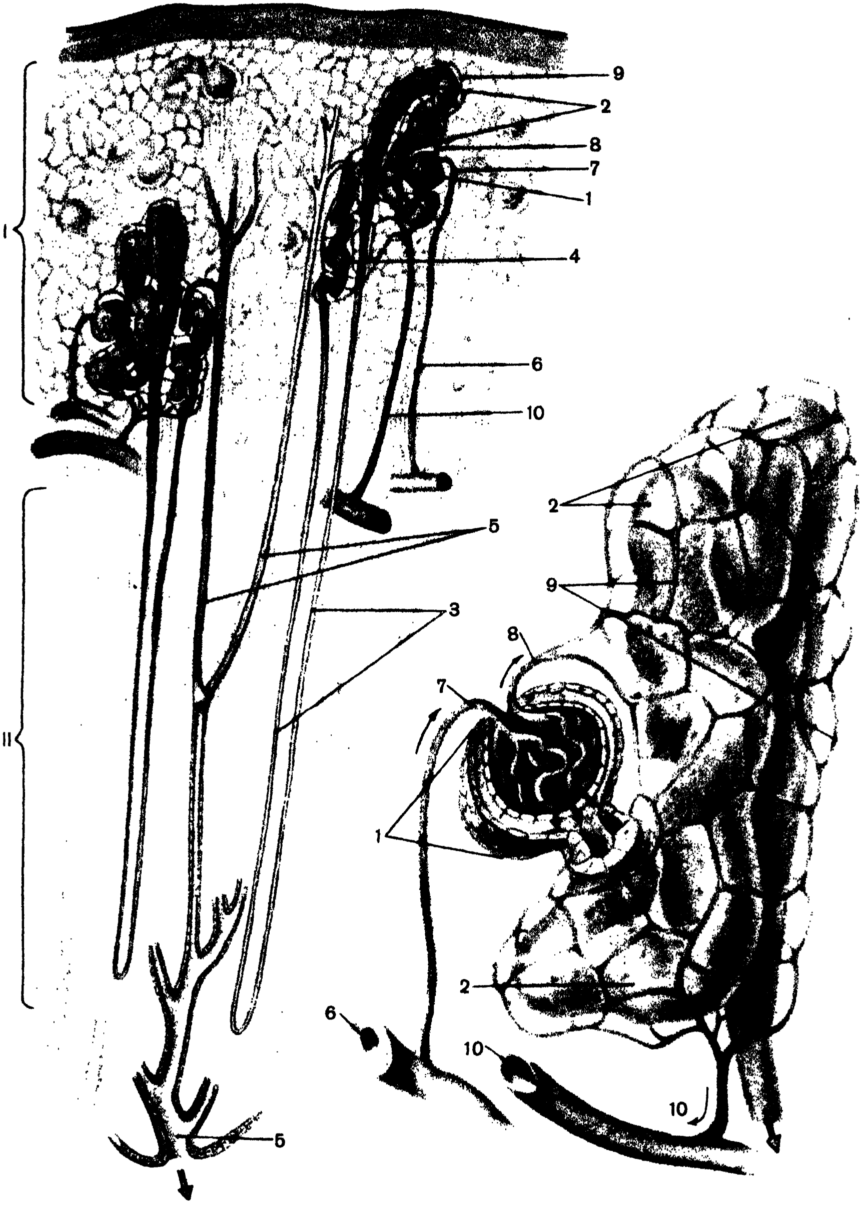

Таблица IV. Микроскопическое строение почки (схема).

Слева-наружный (I) и внутренний (II) слои почки. Справа-при большом увеличении отдельный клубочек с капсулой и началом канальца:

_1_ — капсула с клубочком сосудов в ней; _2_, _3_, _4_ — различные участки канальца; _5_ — трубки, по которым из канальцев моча проходит в почечную лоханку; _6_ — артерия; _7_ — сосуд, приносящий кровь к клубочку; _8_ — сосуд, выносящий кровь из клубочка; _9_ — капилляры, оплетающие канальцы; _10_ — вена.

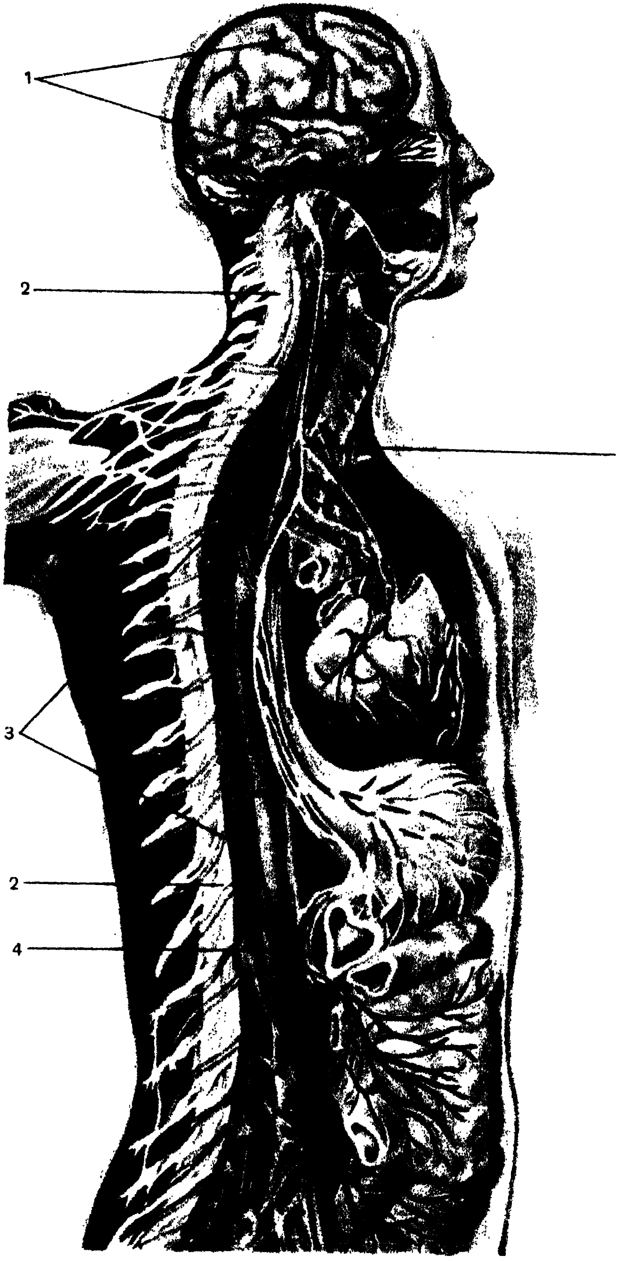

Таблица V. Нервная система человека (схема):

1 — головной мозг; *2* — спинной мозг; *3* — пограничный ствол симпатической системы; *4* — нервные симпатические узлы на аорте (солнечное сплетение); *5* — блуждающий (парасимпатический нерв). Симпатические нервы даны зелёным цветом, парасимпатические — жёлтым, остальные нервы — белым.

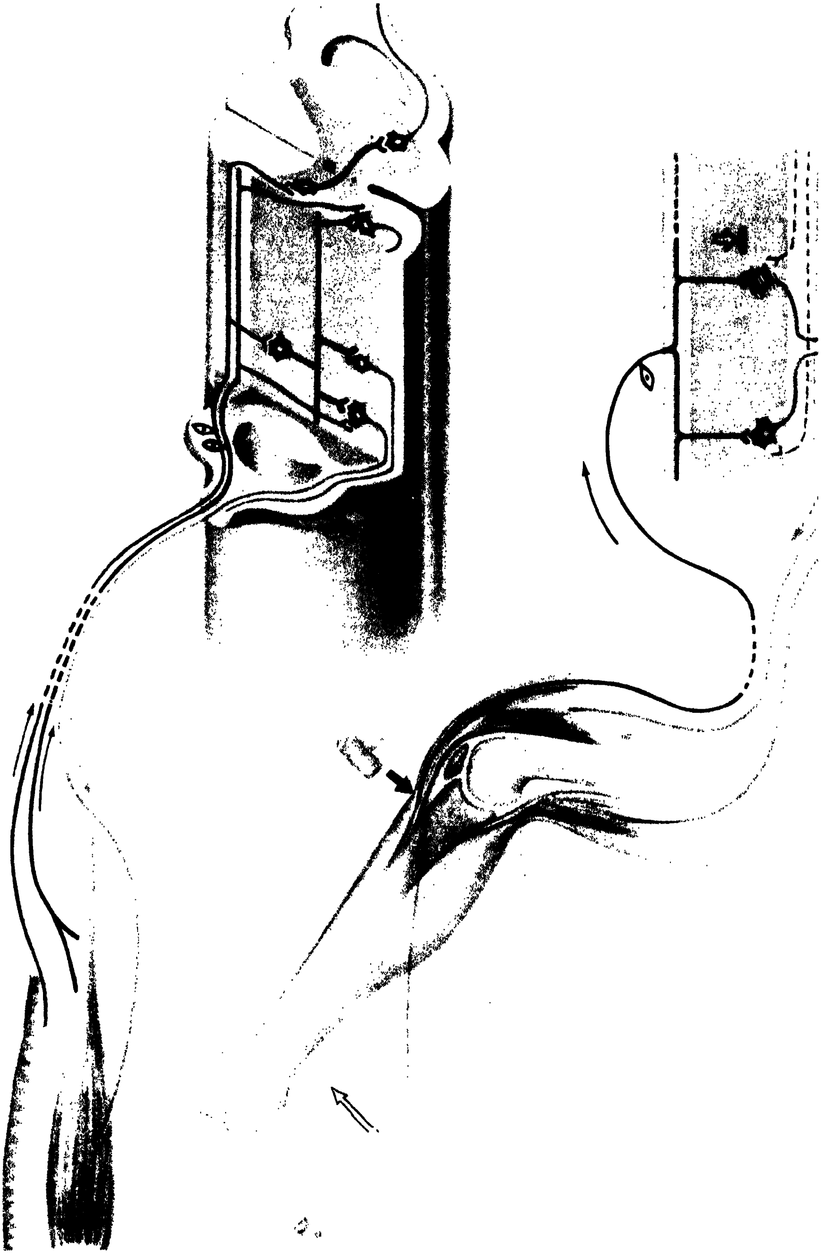

Таблица VI. Схема рефлекса:

Слева-рефлекторные дуги, состоящие из двух и трёх нейронов; справа — схема коленного рефлекса; центробежные нейроны изображены красным цветом, центростремительные — чёрным (от сухожилия) и синим (от кожи), промежуточные — зелёным; стрелки показывают путь рефлекса от сухожилия, через спинной мозг, к мышце; заштрихованный нейрон обозначает торможение центра мышцы противоположного действия.

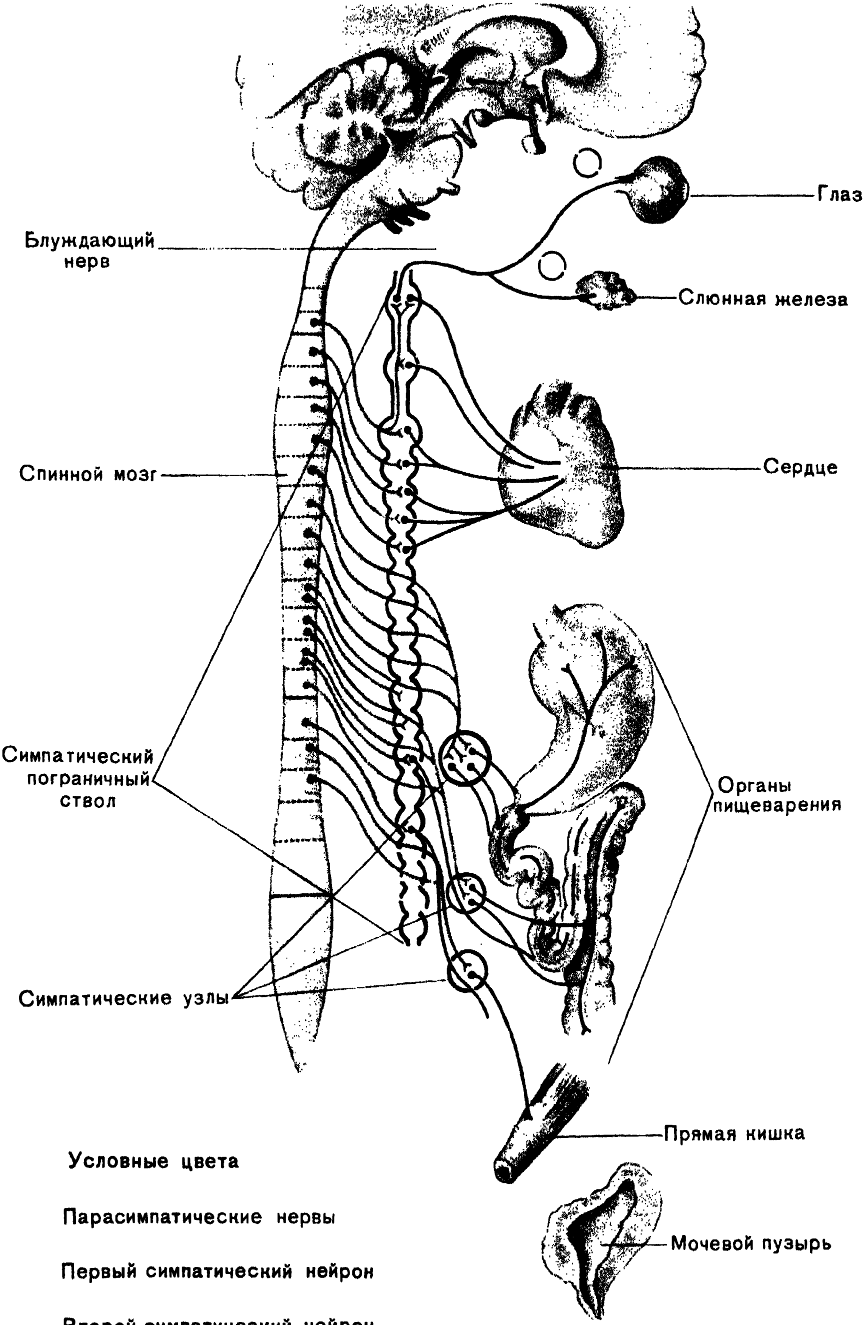

Таблица VII. Схема вегетативной нервной системы.

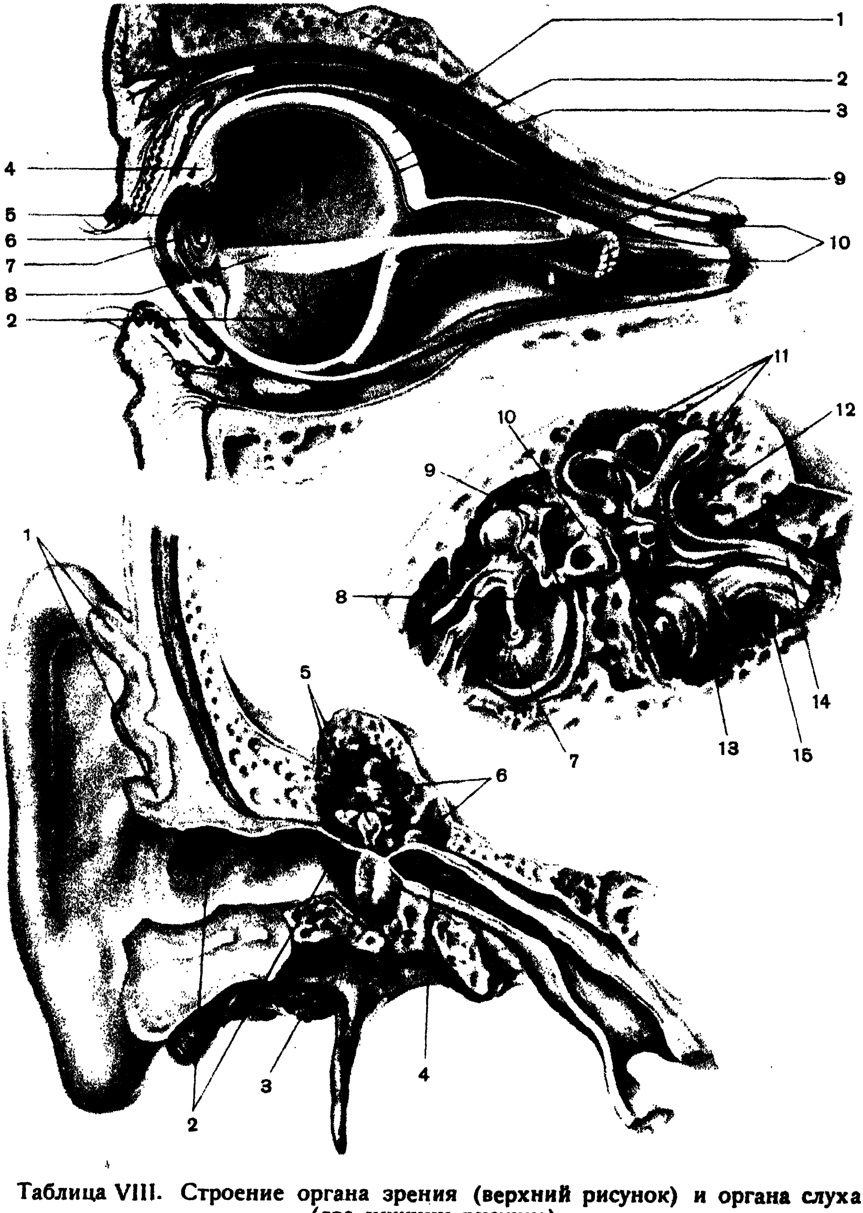

Таблица VIII. Строение органа зрения (верхний рисунок) и органа слуха (два нижних рисунка):

Глаз: *1* — белковая оболочка; *2* — сосудистая оболочка; *3* — сетчатка; *4* — ресничная мышца; *5* — радужная оболочка; *6* — роговица; *7* — хрусталик; *8* — стекловидное тело; *9* — зрительный нерв; *10* — глазные мышцы. Ухо: *1* — хрящ в толще ушной раковины; *2* — наружный слуховой проход; *3* — барабанная перепонка; *4* — евстахиева труба; *5* — среднее ухо; *6* — внутреннее ухо; *7* — внутренняя поверхность барабанной перепонки; *8* — молоточек; *9* — наковальня; *10* — стремя; *11* — полукружные каналы; *12* — отолитовый аппарат; *13* — улитка; *14* — нерв, отходящий от полукружных каналов и отолитового аппарата; *15* — нерв, отходящий от улитки.

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